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WLAN QoS Issues and IEEE 802.11e QoS Enhancement

Prof. Rathnakar Acharya, Dr. V. Vityanathan, Dr. Pethur Raj Chellaih

Abstract—**Wireless communication systems either ad hoc or infrastructure mode the key challenges that must be overcome to realize the practical benefits of Quality of Service (QoS). Generally the QoS is the ability for network element to provide some level of assurance for consistent network data delivery. The ability of Wireless Local Area Network (WLAN) to support real-time services is possible with QoS. IEEE802.11 is a standardized protocol for Wireless LAN (WLAN). To improve the QoS, the original IEEE Medium Access Control (MAC) protocol is enhanced to IEEE 802.11e standard by introducing new coordination functions, which has both contention based and contention free medium access methods. In this paper we evaluated the QoS support of IEEE802.11e standard, by comparing the fairness index and total data carrying capacity of the contention based medium access method, the EDCA and a extension to it a contention free HCF control channel access (HCCA), both are considered to guarantee QoS in WLAN operating in the infrastructure mode.**

Keywords: **WLAN, Quality of Service (QoS), DCF, PCF, HCF, EDCA, HCCA, IEEE802.11e, MAC layer.**

I. Introduction

A wide range of enterprise organizations have realized significant productivity increase by deploying mobile data applications using WLAN **networks**. WLAN technologies are more popular because of simplicity, flexibility and cost effectiveness. Users are now requiring receiving high end web services such as streaming video and audio even when they are moving in office or traveling around the campus. Among these the real time applications such as multimedia services provided by wireless mode requires a good amount of quality of services [5][7] support like; guaranteed bandwidth, delay, jitter and error rate. QoS has different meanings; from the user's perception of the service to a set of network parameters needed to achieve a particular service quality.

IEEE 802.11 is designed for best effort services in WLAN. It specify two MAC mechanisms: the mandatory distributed coordination function (DCF) and optional point coordination function (PCF). Both these mechanisms are not equipped with full-fledged built in system for supporting real time services makes it very difficult to provide the required QoS[7]. The main requirement of IEEE 802.11 WLAN is to guarantee the QoS requirements due to unaware functions such as dedicated bandwidth, controlled jitter and latency. To enhance the QoS support in 802.11 the IEEE 802.11 working group has developed a new standard known as the IEEE 802.11e which introduces the Hybrid Coordination Functions (HCF) with two medium access mechanisms; contention-based channel access and controlled channel access. The contention based channel access is referred to as enhanced distributed channel access (EDCA) and controlled channel access is referred as HCF controlled channel access (HCCA). In this paper we made a comparison of the QoS support provided by both EDCA and HCCA mechanisms of IEEE802.11e standard. We organized the rest of this paper as follows; section 2.0 provides the background of IEEE 802.11 standard for WLAN, section 3.0 we explain the QoS enhancement mechanism used in IEEE 802.11e standard, section 4.0 gives details about the EDCA and its significance in QoS and section 5.0 explains the QoS support provided by HCCA in WLAN followed with conclusion.

Prof. Rathnakar Acharya, Asst. Professor, Alliance Business Academy Bangalore (rathnakar.a@alliancebacademy.org,)
Dr. V. Vaithiyanathan, Professor, Dept. of CSE. SASTRA University Tanjavur (vvn@it.sastra.edu)
Dr. Pethur Raj Chelliah, Senior Software Consultant, Wipro Technologies, Bangalore. (pethuru.chelliah@wipro.com,)

II. IEEE 802.11WLAN

IEEE 802.11 standard covers the MAC sub-layer and the PHY layer of the OSI network reference model for WLANs. The MAC sub-layer defines two medium access coordination functions, the basic DCF and the optional PCF. 802.11 can operate both in contention based DCF mode and contention free PCF mode. A group of station's (STA's) coordinated by DCF and PCF is called as a Basic Service Set (BSS). It is also considered as the coverage area provided by a single access point (AP). In which the AP and mobile stations can communicate using the radio channel with an acceptable minimum quality. The quality can be determined based on the Signal to Noise Ratio (SNR) and other derived matrices such as Frame Error Ratio (FER). In an extended service set (ESS) all or part of these coverage areas can overlap so that a mobile station can select the AP to use; these regions are called re-association or hand off area. The area covered by BSS is known as basic service area (BSA). The core of the IEEE 802.11 standard is the BSS. In 802.11 there are two ways to organize stations of WLAN's: the infrastructure and ad hoc mode.

A. Distributed Coordination Function (DCF)

DCF is the basic medium access mechanism for both add hoc and infrastructure mode. DCF is a distributed medium access scheme based on carrier sense multiple accesses with collision avoidance CSMA/CA protocol. It provides asynchronous transmission in WLAN and its implementation is mandatory in all 802.11. In DCF a STA must sense the medium before initiating a packet transmission. i.e in this mode each station (STA) checks whether the medium is idle before attempting to transmit. The two-carrier sensing mechanisms possible here are: physical (PHY) carrier sensing at the air interface and virtual carrier sensing at the PHY MAC layer. The PHY carrier sensing helps to detect the presence of other STA's by analyzing all detected packets and channel activities via relative signal strength from other STA. Virtual carrier sensing can be used by a STA to inform all other STA's in the same BSS how long the channel will be reserved for its frame transmission. To get this the sender can set a duration field in the MAC header of data frame.

If the medium has been sensed idle for DIFS (Distributed Inter frame Space) period the source station can transmit the packet immediately. In the same time the other station differ their transmission by adjusting their NAVs and then start the $backoff$ process. Decrement the $backoff$ interval counter while the medium is idle. The STA's now computes a random time interval called $backoff$ time selected from the Contention Window (CW).

Its value is; $BackoffTime = Random() \times aSlotTime$

Where Random() - is a pseudorandom integer drawn from a uniform distribution over the interval $[0, CW]$. The range of CW is; $aCW_{\min} \le CW \le CW_{\max}$

$aSlotTime$ - is the value of the correspondingly named PHY characteristic.

In fig.1 it is clear that every time when the transmission fails the CW size increases. This is because the STA wants to avoid collision with frames transmitted by others and if it uses increased CW size the collision probability will decrease. The receiving station sends an Acknowledgement (ACK) packet after a specified time called the Short Inter Frame Space (SIFS) [7] and the CW is reset to a fixed minimum value $CW_{\min}$. The ACK transmitted after SIFS is smaller than DIFS.

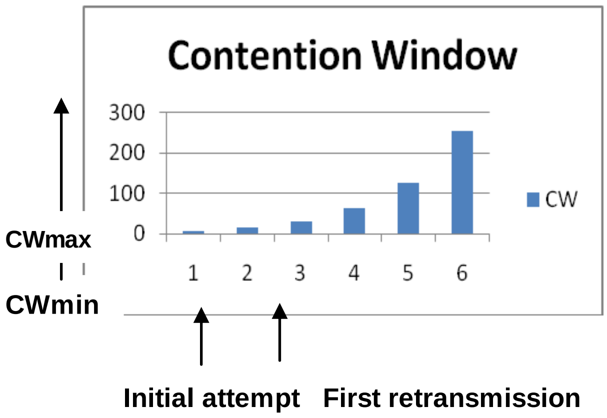

Figure1 changes in contention widow value

If the sender does not receive the ACK, the MAC layer retransmits the frame until it receives the ACK or discards the frame after the number of retransmissions reaches its limit. Other STAs reuse the $backoff$ process after the DIFS idle time. Once the $backoff$ interval has expired the STA begins the transmission. If the transmission is not successful, a collision is considered to have occurred. In this case the CW is doubled and a new $backoff$ procedure start again with the latest $backoff$ counter value. The updated new CW value is $CW = 2(CW+1)-1$, with an upper limit of $CW_{\max}$. This reduces the collision probability in case of many STA's attempting to access the channel.

B. Point Coordination Function (PCF)

PCF uses a centralized polling method, which requires the AP as a point coordinator (PC). PCF supports time bound service in IEEE 802.11 standard to let STA's have contention free access to the wireless medium, coordinated by the PC. The PCF provides synchronous service that basically implements polling based access. It has a higher priority than the DCF, because the period during which the PCF is used protected form the DCF contention via, the Network Allocation Vector (NAV) set. If a BSS is set up with PCF enabled the channel access time is divided into periodic intervals named as beacon intervals. A beacon frame is approximately 50bytes long, with about half of that being a common frame header and cyclic redundancy check (CRC) field. As with other frames the header includes source and destination MAC addresses as well as other information's regarding the communication process. The destination address is always set to all ones, which is the broadcast medium access control address. This forces all other stations on the applicable channel to receive and process each beacon frame. The beacon interval is composed of a contention free period (CFP) and a contention period (CP). During the CFP the PC maintains a list of registered STA's and polls each STA according to its list. The polled station will get the permission for data transformation. Since every STA is permitted to a maximum length of frame to transmit the maximum CFP duration for all the STAs can be known and decided by the PC, which is called $CFP\_\max\_duration$. The time used by the PC to generate beacon frames is called target beacon transmission time (TBTT). In the beacon the PC denotes the next TBTT and broadcast it to all the other STAs in the BSS. To avoid the interrupting of PCF frame the DCF STAs, a PC waits for a PCF Inter frame Space (PIFS), which is shorter than DIFS to start the PCF. Then all other stations set their NAVs to the values of $CFP\_\max\_duration$ time or the remaining duration of CFP in case of delayed beacon. During the CP the DCF scheme is used and the beacon interval must allow at least on DCF data frame to be transmitted.

III. IEEE 802.11E MAC QOS ENHANCEMENT

There are no issues about the QOS [15] in wired networks, because by increasing the bandwidth of the PHY channel the performance can be enhanced. However wireless LAN (WLAN) has some distinct features compared to wired network. It is quite difficult to obtain the higher data rate by using WLAN; due to the higher interference and error rate.

Moreover, high collision rate and frequent retransmission in wireless channel will cause unpredictable delays and jitters, which degrade the quality of real-time voice and video transmission.

A. *IEEE 802.11e and QOS*

The IEEE standard 802.11e provides QoS in two forms [11]. First it supports a priority based effort service similar to Diffserv and in the second it supports parameterized QoS for the benefit of applications requiring QoS for different flows. In IEEE802.11e this is achieved by enhancing the DCF and PCF functionality, and by providing a signaling mechanism for parameterized QoS. IEEE 802.11e includes the enhanced MAC protocols such as enhanced DCF (EDCF) and enhanced PCF (EPCF) [1][7]. Both EDCF and EPCF are commonly referred as Hybrid Coordinated Functions (HCF) [9]. Where EDCF provides the priority based best effort service traffic category. Frames corresponding to different traffic categories are now transmitted through different back off instances. The scheduling of frames for every traffic category has an associated independent back off instance. This scheduling is done the same way as in DCF. Differentiation in the priority is achieved by setting different probabilities for different categories for winning the channel contention. The probability can be changed by varying the values of Arbitration Inter Frame Space (AIFS), where AFIS is the listen interval for channel contention. AIFS is analogous to DIFS period in DCF. For each traffic categories the value of AIFS determines the priority, with lower AIFS values, the listen interval required for channel contention is lower and hence the probability of winning the channel contention is higher.

B. *Hybrid Coordinate Function (HCF)*

IEEE 802.11e defines a single coordination function called hybrid coordination function (HCF) [7] used only in QoS enhance Basic Service Set (QBSS). It provides a hybrid access method approach to achieve a better QoS [7] performance. The HCF combines the contention based and contention free medium access method and replaces the legacy DCF and PCF in a QoS Station (QSTA) [1]. The HCF is composed of two channel access mechanisms:

1) A contention based channel access referred to as the enhanced distributed channel access (EDCA) [3]; which provides distributed access method; it can be viewed as an enhancement of DCF and can be used in both infrastructure mode and ad hoc network.
2) A controlled channel access referred to as the HCF controlled channel access (HCCA) [1], which is controlled by the hybrid coordinator (HC). It provides centralized access method and can be only used in infrastructure network [1]. IEEE 802.11e defines other new features to give better QoS performance. A transmission opportunity (TXOP) [3] is a bounded time interval reserved for a specific STA. If the frame length is shorter than the TXOP, the station is allowed to send as many frames as it can during its TXOPs. If the frame length is larger than the TXOP, the station must fragment the large frame into smaller blocks each of which can be sent in the length of TXOP. The introduction of TXOP reduces the problem of low rate stations gaining an inordinate amount of channel time in the 802.11 legacy DCF.

IV. ENHANCED DISTRIBUTED CHANNEL ACCESS (EDCA)

A. *Prioritized scheduling*

The QoS [7] in a WLAN using DCF is enhanced by EDCA, and it supports priority based best-effort service such as DiffServ. Prioritized QoS is realized through the introduction of four access categories (ACs), [7] which provide delivery of frames associated with user priorities as defined in IEEE 802.1D. Each AC has its own transmit queue and its own set of AC parameters. The differentiation in priority between ACs is achieved by setting different values for the AC parameters. These priority parameters are:

1) **Arbitrary inter-frame space number (AIFSn)**: It is the minimum time interval between the wireless medium becoming idle and the start of transmission of a frame.
2) **Contention Window (CW)**: A random number is drawn from this interval, or window, for the $backoff$ mechanism. The medium access function in each station maintains a $backoff$.
3) **TXOP Limit**: The maximum duration for which a QSTA can transmit after obtaining a TXOP [3].

When data arrives at the MAC-UNITDATA service access point (SAP), the 802.11e MAC first classifies the data with the appropriate AC, and then pushes the newly arrived MAC service data unit (MSDU) into the appropriate AC transmit queue. MSDUs from different ACs contend for EDCA-TXOP internally within the QSTA. The $backoff$ period is calculated by the internal contention algorithm, independently for each AC, based on AIFSn, contention window, and a random number. The AC with the smallest $backoff$ wins the internal contention. The implementation of the external contention window is given in the fig. 2. The winning AC would then contend externally for the wireless medium. he external contention algorithm has not changed significantl Ty compared to DCF, except that in DCF the deferral and $backoff$ is constant for a particular PHY layer. 802.11e has changed the deferral and $backoff$ to be variable and the values are set according to the appropriate AC. The possible implementations with proper tuning of AC parameters and traffic performance from different ACs can be

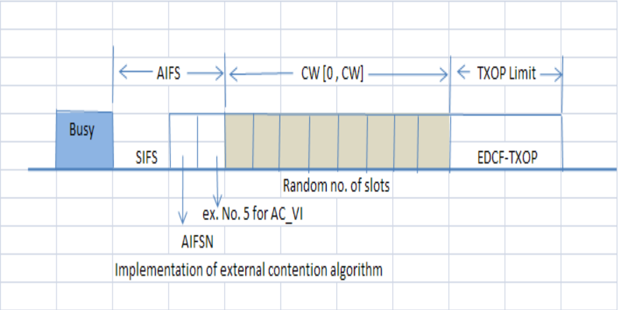

Figure2 Implementation of external contention algorithms

optimized and prioritization of traffic can be achieved. This requires a central coordinator QoS access point (QAP) to maintain a common set of AC parameters to guarantee fairness of access for all QSTA within the QBSS. Also in order to address the asymmetry between uplink (QSTA to QAP) and the much heavier downlink (QAP to QSTA) traffic, a separate set of EDCA

Priority	**User priority (UP)**	**Access Category (AC)**	**Traffic types**
	1	**AC_BK**	**Background traffic**
	2	**AC_BK**	**Background traffic**
	0	**AC_BE**	**Best effort traffic**
	3	**AC_BE**	**Best effort traffic**
	4	**AC_VI**	**Video traffic**
	5	**AC_VI**	**Video traffic**
	6	**AC_VO**	**Voice traffic**
Highest Lowest	**7**	**AC_VO**	**Voice traffic**

TABLEI. .CHANGES IN CONTENTION WIDOW VALUE

parameters is defined for the QAP only, which takes this asymmetry into account. The AC is assigned to each frame before it enters the MAC layer based on its user priority (UP) or its frame type according to the table 1, where the four traffic types corresponding to the four AC's are given.

The table contains 8 user priorities (Ups). Either each MSDU has user priority (UP) values or a traffic specification (TSPEC). The traffic identification (TID) field values 0-7 are designated to UP. TID field values 8-15(not given in the table) are interpreted as traffic stream (TS) identifiers and designated to TSPEC. MSDU are permitted to reorder in the MAC layer which allows it to implement priority.

EDCF channel access defines the AC mechanism that provides support for the priorities at different STA's. Each STA may have up to four ACs to support eight priority traffic categories (TCs). One or more TCs are assigned to one AC. A STA access the medium based on the AC of the frame that is to be transmitted. The prioritized medium access of EDCF [9] is realized by assigning different arbitration inter-frame space (AIFS) and contention window (CW) to different ACs. An AC with higher priority is assigned a smaller AIFS and shorter CW in order to ensure that, in more cases higher priority ACs will be able to transmit before the low priority ones. Since each AC is implemented as a virtual station, the collision rate increases quickly as the number of STAs increases. This will degrade the network throughput and increase medium access delay. To protect the existing data flows IEEE802.11e also includes distributed admission control procedure. In the procedure AP increases the amount of the time occupied by transmission for each AC during each beacon interval. The AP then computes the transmission budget for each AC by subtracting the occupied time frame the transmission limit of this AC. When the transmission budget for an AC is depleted new node will not be able to gain transmission time and existing node will not be able to increase the transmission time that they are already using the next beacon period.

This method of Admission control is based on the measurement of the existing traffic over IEEE 802.11e network. The purpose of any admission control is to ensure that entry of a new data flow into a resource limited network to the admitted data flows while optimizing the network resource usage. In this method each STA measures the traffic load on the wireless medium. Depending on the amount of existing traffic load and priority level of the data packets waiting for transmission, the admission controller make decision on whether or not to allow the data unit to have the right access the wireless medium.

In IEEE 802.11e standard each station may have up to four ACs. This is represented as;

$AC_{(i)} i = 0,1,2,3$. In which $AC_{(3)}$ has the highest priority and $AC_{(0)}$ processes the lowest priority.

When the traffic condition in a wireless medium reach greater than the threshold value (i.e the wireless network is experiencing the overloading) results in medium access delay and possible the degradation of throughput. The STAs stops the transmission of low priority data to ensure that high priority data flows continue to be received for their required QoS as much as possible. When the network traffic decreases the stations will resume the transmission of the stopped data flow to increase the network performance.

An enhanced variant of the DCF the Enhanced Distributed Channel Access Function (EDCAF) is assigned to each AC. These ACs to contend for medium access has to use it. The AC parameter set contains the following parameters: arbitrary interframe space number (AIFSn), the number of time slots after a SIFS duration that a station has to defer before either invoking a $backoff$ or starting a transmission. AIFSn affects the arbitration interframe space (AIFS), which specifies the duration (in time instead of number of time slots) a station, must defer before $backoff$ or transmission:

$$AIFS = SIFS + AIFSn \times aSlotTime$$

Where $AIFSn$ depends on AC and the value of $aSlotTime$ depends on the physical layer the 802.11e used. The $backoff$ procedure is uniformly distributed between $(0\, and\, Cw-1)$. CW value is between $CW_{\min}$ and $CW_{\max}$. After a successful transmission CW value is reset to $CW_{\min}$ and when the packet result in collision the back of procedure doubles the CW value until the value reaches to $CW_{\max}$. So an AC with lower value of AIFSn has less AIFS and is thus given a high priority.

Contention Window (CW): a random number is drawn from this interval for calculating the total *backoff* as:

$$Backoff = AIFS + random[CW_{\min} : CW_{\max}]$$

An AC with lower values of $CW_{\min}$ and $CW_{\max}$ has higher probability to draw a smaller random number, thus it is given higher priority. The EDCA performs a prioritized medium access. The QoS support is provided with the introduction of AC's. In EDCA relative priorities are provisional by configuring the time to access the channel. Once it is sensed idle defined as arbitrary interframe space (AIFS's). which determines the priority.

Each AC performs contention and *backoff* independently from other ACs at the STA. EDCA provides a differentiated channel access, which is realized by varying the size of the contention window and the time spent for sensing the channel. The contention handling system in EDCA is essentially a contention based MAC protocol. Before the message transmission it must first sense that the channel is idle for a time period known as Arbitration Interframe Space (AIFS) and then restrains itself from transmitting for a random length of time known as $Backoff\ (Bn)$. The value of AIFS and Bn depends on the AC of the traffic to be transmitted. Where the highest priority AC has the smallest AIFS, and the lowest priority traffic has the largest AIFS. This means that the highest priority traffic has a better chance of accessing the channel more quickly. EDCA uses the CW to assign priority to each AC.

Indeed assigning a short CW to a high priority AC ensures that in most cases, high priority AC is able to transmit ahead of low priority one. The size of the CW also varies for each AC. The CW size determines for how long a node will *backoff* before attempting to gain access to the channel. The fig.3 below illustrates the different queues for different priorities AC's.

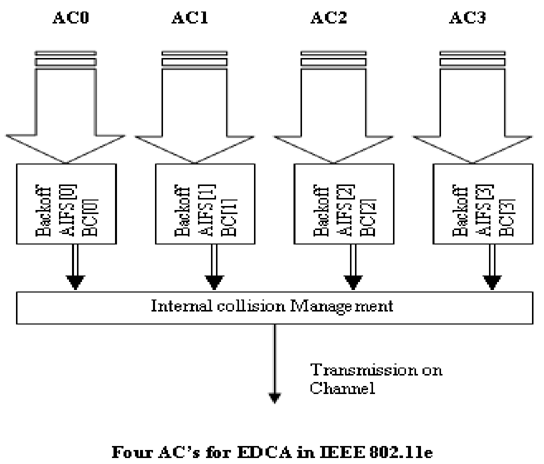

Figure3 Four AC's for EDCA in IEEE802.11e

The priority of the traffic to be transmitted is determined by the value of Channel Access Delay (CAD). Higher the priority of the traffic to be transmitted lower is the CAD. The CAD has three components; a fixed length DIFS, and variable length AIFS and CW. The channel access delay is estimated as;

$$AIFS = \eta DIFS$$

Where $\eta = 1,2,3.......$ and it depends on the traffic class

$$CW = (2^{r+n-1} - 1) * slot\_length$$

Where $n = n^{th}$ transmission attempt

$r =$ a factor that depends on the traffic type, when the r value is lower the priority of the traffic is higher.

$$CAD = AIFS + Bn \quad \text{for} \quad 0 \le Bn \le CW$$

Once a device has gained access to the wireless medium, it has the opportunity to continue transmitting for a specified transmission opportunity (TXOP). Applications or packets that share the same AC also have the same maximum *Backoff* time and, hence, the same chance to gain access to the wireless medium. EDCA is fairly simple to implement, but cannot guarantee latency, jitter or bandwidth and has no means to handle several applications with the same priority level. We analyzed the QoS enhancement scheme through ns-2 simulation. It provides the information about the number of collision/sec and the fairness index of EDCA are shown in fig 4 and fig.5. The QoS mechanism provided by EDCA is not enough to support for delay-bound multimedia applications. Also EDCA is known to perform poorly during high channel load, because of the excessively high contention rate. This can be overcome by using Adaptive EDCA (AEDCA), where an AEDCA can provide better QoS support for multimedia applications than EDCA in medium and high load cases.

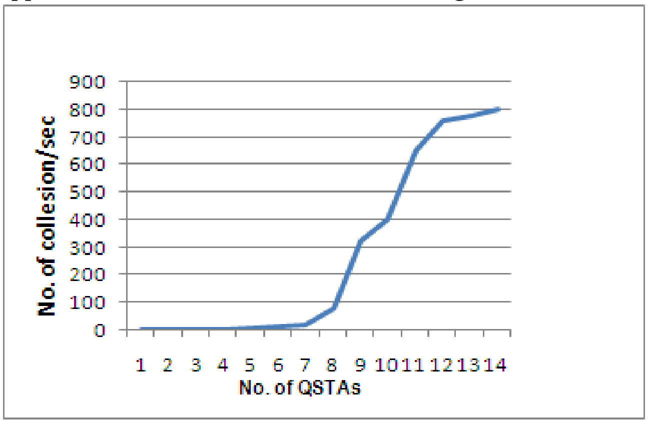

Figure4 No. of collisions per second using EDCA

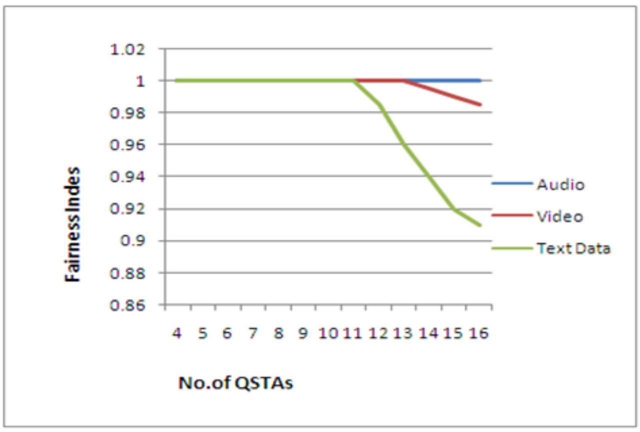

Figure5 Fairness index for EDCAIEEE802.11e

V. HCF CONTROLLED Channel Access (Hcca)

HCCA uses another approach to guarantee QoS [1][7]. Instead of waiting for idle time for transmission and using a $Backoff$ mechanism, it relies on a centralized control in the access point (functioning as the HC- Hybrid Coordinator) that can guarantee the time and duration of the transmission for each of the connected stations. A HC is needed, because which has the highest channel access priority to contend the channel and allocate transmission opportunity (TXOP) to stations. In a WLAN having HCF polling mode, a HC act as the major control STA. The AP usually takes up the function of HC in the infrastructure mode, where as in an ad-hoc wireless network a HC should be decided by some algorithms.

The HC in a QoS access point (QAP) receives the traffic requirements sent by the QSTAs. If the traffic can be scheduled in the HCCA mode, the QSTA receives a downlink frame notifying the acceptance of the traffic. Then a virtual connection called traffic streams (TS) is established and the QSTA receives a TXOP of certain duration each time it is polled by the QAP. Thus a QSTA can use the channel and send the packets.

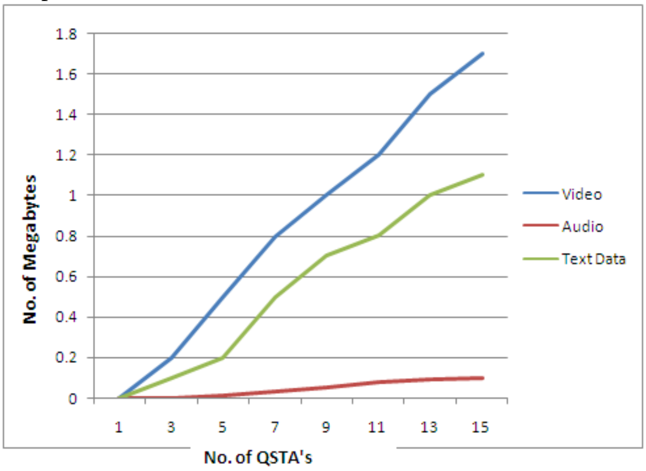

Figure6 Total Mega bytes of data received in HCCA method

With the QoS request the QAP determines the minimum of all the service intervals (SIs) required by different traffic streams applying for HCCA. Then it computes the highest sub-multiple of the super-fame duration. Which is inferior to the minimum of all SIs. Thus the super-frame is divided into several SIs and QSTAs are polled according to round robin algorithm during each SI. Once the SI is determined, the QAP computes the different TXOPs which are to be allocated to the QSTAs. TXOP reflects the time duration to transmit the number of packets arriving during a SI in a TS queue. The number of packets in a TS queue j of a QSTA i during a SI is;

$$N_{i,j} = \frac{\rho_{i,j} \times SI}{M_{i,j}}$$

Where $\rho_{i,j}$ is the data rate of application and $M_{i,j}$ is the size of MSDU. So the TXOP of the traffic is calculated as

$$TXOP = N_{i,j}\left[\frac{M_{i,j}}{R} + 2 \times SIFS + ACK\right]$$

R is the physical transmission rate, SIFS-short inter-frame space and ACK is the time to transmit an acknowledgement packet, $N_{i,j}$ is the number of packets in the current TS queue. During one TXOP the packets are stored in the TS queue, since last transmission should all be transmitted after receiving polling for this transmission by the QAP. The TXOP allocation scheme ensures that the queue length of each TS having been polled is either constant if $N_{i,j}$ is an integer, or slowly decreasing in each rounds of polling by the QAP. Fig. 6 gives the amount of data received by a HCCA enabled AP for different types of data.

HCCA can provide more strict QoS support than EDCA, but it is (EDCA) still mandatory in IEEE802.11e that, for supporting QoS specification exchange between QSTA's and QAP.

VI. CONCLUSION

In this paper we have presented the MAC layer QoS mechanisms provided in IEEE 802.11e standard for WLAN. The MAC layer QOS mechanism make the 802.11e standard a very powerful platform to support QoS in WLANs for real time applications. Among the various coordinate functions such as EDCA and HCCA the survey compares the 802.11e's contentions free medium access method the EDCA cannot provide any QoS guarantee. Through simulation it is clear that the performance of EDCA is less when the traffic load is very high.

The HCCA is a centralized control mechanism; it is applicable to infrastructure mode. It provides a deterministic QoS performance for applications with admission control, while EDCA only provide statistical QoS performance. This is due to HCCA is contention free and EDCA is contentions based. The admission control in EDCA can be used to both Infrastructure and ad hoc mode. In a mixed HCCA and EDCA scenario it is very challenging to tradeoff between EDCA and HCCA. The aim in future work will be to further compare HCCA and EDCA and determine which one will be the best requirement to obtain the required QoS.

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Dr. V. Vaithiynathan, is a Professor in the Department of Computer Science and Engineering at SASTRA University Tanjavur India. Prof. Rathnakar Acharya Graduate in Electrical an Electronic Engg, from Mysore University and Post Graduate in Technology and Management. Having 19 years, of experience in teaching/ research. Presently perusing research (PhD) in QoS issues in WLAN.

Dr. Pethur Raj Chelliah, PhD from Anna University, India, worked as a research associate at the Dept. of Computer Science and Automation at IISc. Bangalore and then Postdoctoral research at Japan (Nagaya Institute of Technology Kyoto University and University of Tsukuba) currently working as senior consultant (SOA Evangelist) at Wipro Technologies Bangalore.