Improving the Performance of IEEE 802.11e with an Advanced Scheduling Heuristic

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Abstract. The new standard IEEE 802.11e targets at enhancing the legacy 802.11 so that QoS management over WLAN standards becomes possible. This is done by the introduction of two new functions, the enhanced distributed channel access (EDCA) and the hybrid coordination function controlled channel access (HCCA) for offering diffserv and intserv functionalities. The efficient coordination of both functions plays a crucial role in terms of the performance of 802.11e. In this paper we propose a new method for the calculation of the service interval by using the send rates of different traffic streams and suggest an advanced way to determine which one of the functions for which kind of streams to deploy. We show that despite its simplicity the proposed methods decrease packet delay and loss rates significantly and increases the number of streams having acceptable QoS levels.

1 Introduction

802.11 standards are among the most prominent wireless communication technologies for daily use. However the lack of quality of service support on 802.11 does not allow sufficient protection for real time traffic for which there is a high demand on the customer side. In order to overcome this problem, the IEEE 802.11e task group developed an amendment to the legacy 802.11 standard. The amendment targets at enhancing the legacy 802.11 medium access control so that real time traffic can be offered using WLAN devices within acceptable quality of service levels.

The most dominant enhancement in 802.11 medium access control (MAC) is the introduction of the hybrid coordination function (HCF) which consists of two sub functions, the enhanced distributed channel access (EDCA) and the HCF controlled channel access (HCCA). As the 802.11e standard is new, most of the relevant studies made so far include performance analysis and the improvement suggestions for the new functions EDCA and HCCA [1–3]. In these studies, it was shown that although the new standard improves the WLAN performance substantially, only a very careful fine tuning of the parameters of these functions results high QoS levels. In our previous study [4], we also showed that especially the maximum service interval (maximum allowed time between transmissions of two successive packets belonging to a specific traffic stream) and the amount of time reserved for HCCA affect the QoS that one may expect using 802.11e. The correct choice of these parameters boosts system performance drastically. Although the effects of the service interval choice and the time reserved for HCCA were shown to be significantly high in [4], no method was proposed for a proper selection of these parameters.

In this paper we analyze mathematically the effect of the service interval choice on the delay and loss rates of the traffic being served within HCCA and correspondingly propose methods for choosing service interval length leading to significant performance improvements. We also propose an admission control algorithm which is an enhanced version of the reference admission control of 802.11e. Within the proposed admission control algorithm, we differentiate between uplink, downlink and bidirectional traffic. We figure out in which cases these different traffic types should be assigned to which one of the two sub functions (EDCA and HCCA) of the hybrid coordination function. We show that the cooperation and so the performance of 802.11e in terms of offered QoS can be significantly increased when using this control mechanism and the service interval selection method. To the best of the authors' knowledge there is no study which deals with the service interval selection problem and a corresponding admission control procedure although it is one of the most effective parameters of 802.11e in terms of satisfying QoS requirements [4].

The rest of the paper is organized as follows. In the second section the functioning of HCCA is summarized in order to give background information about 802.11e. In the third section a short literature review is given. In the fourth section we analyze the relationship between service interval and the QoS metrics. Fifth section presents the validation of mathematical analysis with simulation results. In the sixth section we draw the conclusions.

2 Background

The IEEE 802.11e task group enhanced the legacy WLAN standard with two well known QoS mechanisms. These mechanisms are called differentiated services (diffserv) and integrated services (intserv). Diffserv mechanism is setup in the way that access points can serve multiple traffic classes with different QoS requirements. Instead of priorities, intserv is based on the individual QoS requirements of the stations. The hybrid coordination function of 802.11e uses EDCA for diffserv and HCCA for intserv. Depending on the load of the network, hybrid coordination function determines respectively at what time which one of these functions to use. An example to successive deployment of EDCA and HCCA can be seen in figure 1.

Basically the HCCA is an asynchronous real time scheduler. For cases where there are strict delay and loss constraints, the stations inform the access point that they must be included in the HCCA scheduler. In order to do this, they give detailed information about the traffic stream within a management frame called TSPEC. TSPEC includes information like nominal MAC service data unit (MSDU) size, mean data rate, suspension interval, delay, surplus bandwidth

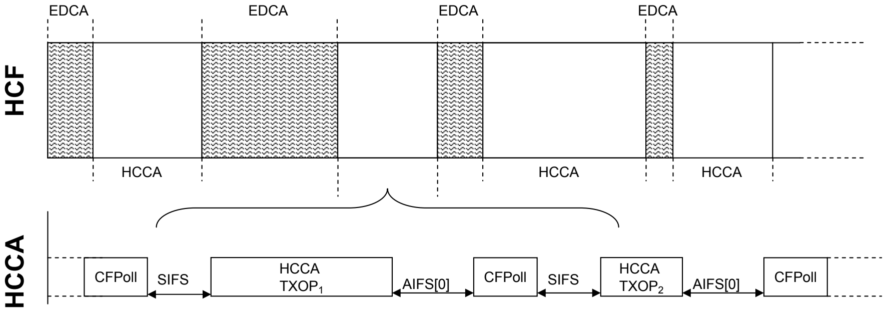


Fig. 1. An illustration of HCF, HCCA and EDCA

allowance and maximum service interval. This information is used to decide on accepting the incoming requests for being included in the schedule of HCCA or not. If a stream is accepted to the HCCA schedule, then a time interval for that specific stream is reserved in the schedule. This time interval is called the HCCA transmission opportunity (HCCA TXOP). The usage of HCCA TXOP is summarized in Fig. 1. Stations are informed about the reserved TXOP with a frame called CFPoll frame after the channel is sensed to be idle for a time period which is called the arbitration inter frame space (AIFS). In fact AIFS is different for all traffic priorities. For this reason the arbitration interframe space of the access point is denoted as AIFS[0] within Fig. 1. The station receiving the CFPoll sends its frames after waiting for a short inter frame space (SIFS). During a TXOP only the station which received the CFPoll can send its frames. This period is also called the contention free period, because only the stations who receive HCCA TXOP are allowed to transmit any packets.

In real time schedulers one of the most common and most important parameters used for building the schedule is the deadline. The HCCA reference scheduler uses the maximum service intervals that are given by the stations for this purpose. Maximum service intervals define the maximum amount of time that is allowed between transmissions of two successive frames of a specific stream. For the sake of simplicity, the reference scheduler proposes a cyclic schedule which cycles through a path of TXOPs determined at the beginning of a beacon period (See Fig. 2). This cycling is delineated as follows. A beacon period is defined as the time between two beacon frames where a beacon frame is a management frame used to advertise general information regarding the access point to all surrounding stations periodically. The reference scheduler selects a number as its service interval which is smaller than the smallest maximum service interval given by the stations and which is a submultiple of the beacon interval. In this way it makes sure that all of the maximum service intervals (in other words 'due dates') are taken into account. HCCA calculates TXOPs needed by each one of the stations during one service interval. The same TXOPs are distributed to the stations during each of the following service intervals until a new set of TXOPs is determined. This cyclic procedure is illustrated within Fig. 2 where three different traffic streams receive TXOPs at the beginning of each service interval. As seen from Fig. 2 the time in which HCCA is not used is reserved to EDCA. For more information about the functioning of EDCA please refer to [5].

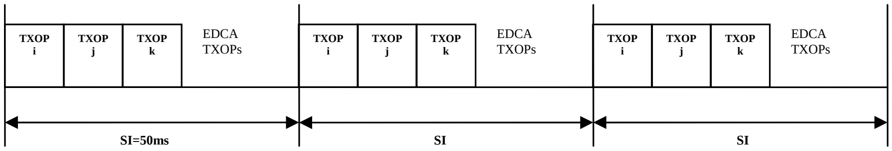


Fig. 2. TXOP distribution for three streams named as i,j and k

3 Literature Review

Due to the long lasting ratification of 802.11e, one can find many studies for the optimization of EDCA and HCCA. To the best of the authors' knowledge, in all these studies, except the one from Ramos et al. [6], EDCA and HCCA were dealt with separately. Banchs et al. [7] introduced an admission control algorithm based on an analytical model for the throughput performance of 802.11e using EDCA, where they dynamically adapt the contention windows of each priority level, as new traffic associates with an access point. On the other hand Xiao [8] presented an enhancement suggestion by introducing "TXOP Budgets" to each access category. In this way, they protect voice and video traffic from the best effort traffic. Kim and Suh [9] and Gao et al. [10] instead use the physical transmission rates of the stations in order to prevent unfairness because of distance at the cost of lower throughput.

For HCCA, the studies concentrate more on the protection of voice and video traffic. Ma et al. [11] use the talkspurt-silence alternation characteristics in order not to reserve time in the HCCA scheduler for a voice stream when it is silent. Ansel et al. [12] and Fan et al. [13] introduce algorithms for dealing with variable bit rate traffic (VBR), as it is one of the main problems of HCCA. As a result of these studies the recommended TXOP calculation of 802.11e was changed so that VBR is also supported. [12] uses exponential smoothing for estimating queue length information of VBR traffic and reassigns TXOPs in case of deviation from the ideal queue length. [13] makes the redistribution of TXOPs by calculating VBR traffic drop rates with a trade-off between the packet loss performance and the number of admitted flows.

Different than EDCA and HCCA performance analysis, in [4] we evaluated the quality of the QBSS load element of 802.11e in terms of an information element for solving the candidate access point selection. It was shown that the complexity of the cooperation of EDCA and HCCA avoids having reliable information for estimating the QoS that a traffic stream can receive after associating with an access point. The service interval and the amount of time reserved for HCCA plays a crucial role in this problem. Taking this result as the basis, we tried to find out the optimum choice of service interval length and the amount of time reserved for HCCA. This paper is devoted to present the results of our studies for increasing 802.11e system performance by adapting a new service interval selection mechanism and time reservation policy for HCCA.

4 Service Interval and the QoS metrics

A service interval starts with the distribution of TXOPs which are determined as follows: Let N_i be the number of packets arriving within a service interval SI, p_i is the application data rate and L_i is the nominal MSDU size of the traffic stream (TS) in TS queue i, then :

$$N_i = \lceil \frac{p_i * SI}{L_i} \rceil. \tag{1}$$

TXOPs for different traffic streams are assigned as follows:

$$TXOP_i = max(\frac{N_i * L_i}{R_i} + O, \frac{M}{R_i} + O), \tag{2}$$

which is the maximum time needed to transmit N frames of size L with data rate R and time needed to send one maximum size MSDU (M) plus overheads. The hybrid coordinator sends the so called CFPoll frames to the stations which includes the information about the assigned TXOP. As given in Fig. 1, the station receiving CFPoll sends its packets after waiting SIFS (short inter frame space) long. In case there is no packet to be transmitted or the excess TXOP is not needed any more, the station sends QoS NULL packet so that next station in the schedule can transmit its packets. For the usage of the given TXOPs there are three possible cases:

- TXOP is used completely, so that there is no free time to send QoS NULL packet at the end
- TXOP is used partially and a QoS NULL packet is sent following a QoS DATA
- TXOP is not used and a QoS NULL packet is sent directly

Although first case is the ideal case, it is not the most usual one because TXOP reservation mechanism rounds up the expected number of packets during a service interval (See eq. (1)). For this reason, there is most of the times unused TXOP for any stream. The expected ratio of unused TXOPs can be given as follows. For a stream with a send rate of x and a service interval length of x+y where y is a positive number, the average number of TXOPs that are not used during a service interval is:

$$NU_{small} = (\frac{N_i}{x+y} - \frac{1}{x}) * (x+y). \tag{3}$$

For a stream with a send rate of z which is greater than or equal to the service interval (x+y), the average number of TXOPs that are not used is:

$$NU_{big} = (\frac{1}{x+y} - \frac{1}{z}) * (x+y). \tag{4}$$

Then the average time used by HCCA during one service interval is:

$$HCCA[y] = Lost[y] + Used[y], \tag{5}$$

where

$$Lost[y] = (\frac{1}{x+y} - \frac{1}{z}) * n_i * nothing_i + (\frac{N_i}{x+y} - \frac{1}{x}) * n_j * nothing_j) * (x+y), \tag{6}$$

$$Used[y] = n_i * TXOP_i * \frac{x+y}{x} + n_j * TXOP_j * \frac{x+y}{z}. \tag{7}$$

For the sake of simplicity we assume that there are only two types of streams, one having a send rate smaller than the service interval and the other one bigger than the service interval. n_i and n_j are the numbers of traffic streams of the first and the second types and $nothing_i$ and $nothing_j$ are the lengths of the times needed for sending QoS NULL frames with the overheads.

As long as there is enough time reserved in the scheduler for any traffic, packet losses should not occur for that traffic. For this reason, in such cases the length of the service interval and so the lost time because of extra TXOP does not play a role in the packet loss rate. However Lost[y] is decreasing in y. Hence, any reduction in the lost time will result lower packet loss rates within a congested channel. We can then estimate the necessary increment in the length of the service interval for a new traffic by finding the increment in the unused time within HCCA scheduler:

$$r*(x+y+k) - HCCA[x+y+k] - (r*(x+y) - HCCA[x+y]) = TXOP_{new}, \tag{8}$$

where r is the maximum percentage of time that can be reserved for HCCA scheduler within a service interval and k the required increment in the service interval length, so that new stream can be served using HCCA. Rather long algebra gives the following solution for k:

$$\frac{TXOP_{new} * x * z}{r * x * z - z * n_i * (T_i - nothing_i) - x * n_j * (T_j - nothing_j)} = k, \tag{9}$$

where T_i is the time needed to send one MSDU plus overheads. Although this equation is harder to solve if there are more than two types of traffic streams to consider, the problem could be reduced to the first priority streams in such cases.

Average delay for the packets is also independent of the lost time, since TXOP distribution is cyclic and the order of TXOP distribution is the same for each service interval. As seen from Fig. 2, the average length between two TXOPs of any specific traffic is the addition of the expected time spent for HCCA plus the remaining time for EDCA. This length is equal to the service interval length. Consequently the average time between two TXOPs of any stream is always equal to the service interval length.

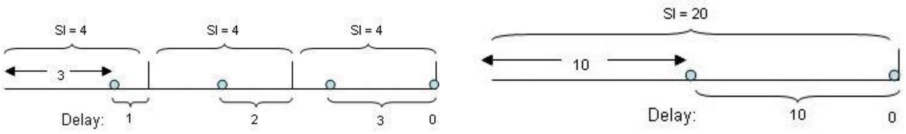
Average delay caused by this service interval is increasing in the length of the service interval and dependent on the number of common divisors of the send rate and the service interval. The simple logic behind this fact is the wasted time because of the asynchronous occurences of the TXOPs and the packet arrivals. In the worst case they have no common divisors. A simple example is illustrated in Fig. 3(a) where the service interval length is 4ms and the send rate is 3 ms. Here, the first packet waits for 1ms to be sent, the second packet waits for 2ms, the third packet 3ms and the last packet is sent directly. Consequently, packets experience delays from 0 to service interval minus one (Here from zero to 3ms). Hence, the average delay is the addition of the integers from 1 to service interval minus one divided by the number of packets experiencing these delays, which is equal to the length of the service interval. This gives the average delay as (SI-1)/2. This implies the fact that each increment in the service interval length also increases the delay of the packets as much as half of this increment. Hence service interval should be kept as small as possible.

The best case scenario is where the interarrival rate or the service interval is a divisor of the other. In this case, if the service interval is longer than the interarrival rate, average delay is (SI-interarrival rate)/2. Fig. 4 illustrates the case where interarrival rate is equal to 10ms. As seen from Fig. 4, we are indifferent between choosing a service interval which is one more than any multiple of the interarrival rate and the next multiple of the interarrival rate. This implies the following point: if we need extra time for a new stream, then we can increase the service interval length to the next multiple without increasing the expected delay. This is achieved by synchronizing TXOPs distributions with the packet arrival times as much as possible. In case there are more than one interarrival rate, decision should be made using delay constraints of the streams. However using the smallest interarrival rate as the basic rate would make sense for most cases, since the number of sent packets is the most for the stream having the smallest interarrival rate.

To summarize our findings:

- Choose the smallest comman multiple/submultiple of the interarrival rates, which is also greater than or equal to the smallest interarrival rate, as the service interval length.
- If we have to increase the service interval length because of a new stream, then we choose the next multiple of the interarrival rates which is also greater than the result of the equation (9).

These two points are used during our simulations in section 6 to select the appropriate service interval.



(a) (b)

Fig. 3. Delay caused by 4ms and 20ms SIs to packets with interarrival rates of 3ms and 10ms

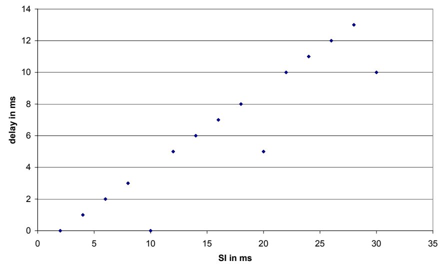


Fig. 4. Delay caused by different SIs to a packet with a interarrival rate of 10ms

5 Assigning traffic streams to HCCA and EDCA

So far we analyzed the effect of the service interval to loss and delay of the traffic streams served within HCCA. In this section we clarify which type of traffic should be assigned to HCCA during admission control processes.

The access point accesses the channel like a station when using EDCA. Having only as much channel access chance as a station with the load of all stations impairs downlink traffic drastically. In case the TXOP given to access point for any priority is not enough, then especially the interface queue length increases substantially leading to high delay and even loss rates. For this reason it is reasonable to protect the downlink traffic during HCCA, and only if there is remaining time in the HCCA scheduler reserve it for the uplink traffic. However it can be shown using simple calculations that as long as the overhead for sending the needed amount of packets using HCCA is higher, it makes no sense to reserve time for uplink traffic in the scheduler within a congested channel. If we describe the total time usage (TT) within a service interval as:

$$TT = \sum_{j=1}^{3}\sum_{i=1}^{j} N_{j,i} * p_{j,i} + \sum_{j=1}^{3}\sum_{i=1}^{j}((\frac{SI}{x_{j,i}} - N_{j,i}) * q_{j,i}) + B, \tag{10}$$

where $N_{j,i}$ is the number of packets from the i^{th} stream of the j^{th} priority allowed to be transmitted using HCCA, $p_{j,i}$ is the amount of time needed to send one packet during HCCA and respectively $q_{j,i}$ is the time needed during

EDCA, $x_{j,i}$ is the interarrival rate and B is the time used by traffic which did not request any HCCA TXOP, which was rejected by the HCCA scheduler and the background traffic. The summation is done over three priorities, since background traffic does not receive HCCA TXOP. Using this equation one can find the effect of reserving TXOP for an additional packet:

$$\partial_{N_{j,i}} TT = \sum_{j=1}^{3}\sum_{i=1}^{j} p_{j,i} - \sum_{j=1}^{3}\sum_{i=1}^{j} q_{j,i}. \tag{11}$$

As seen, the slope of the total time usage with respect to $N_{j,i}$ is dependent on the packet transmission times required for EDCA and HCCA. If the time needed to send the same packet during HCCA is longer than the time needed to send the same packet during EDCA, than reserving time in the HCCA for this packet causes more channel utilization because of the increasing TT (total time usage). The time needed to send one packet during HCCA and EDCA can be illustrated as follows:

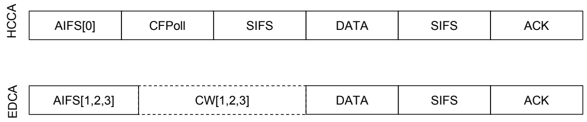


Fig. 5. Comparison of packet transmission times with EDCA and HCCA

In Fig. 5 each block represents the time needed for different actions. AIFS[0] is the length of the arbitration inter frame space used by the access point. CFPoll is the time needed to send one CFPoll frame, ACK is the time needed to send the acknowledgment, and CW is the contention window length. We include AIFS and CW of the first three priorities as the fourth priority uses only EDCA for its transmissions. If we compare both cases, we see that the difference of the times needed by HCCA and EDCA to send the same packet is AIFS[0]+ CFPoll + SIFS <> AIFS[1,2,3]+CW[1,2,3]. The assignment of the lengths of arbitration inter frame spaces is described in the standard as follows:

$$AIFS[AC] = AIFSN[AC] * slotTime + SIFS, \tag{12}$$

where AIFSN[AC] is a number greater than or equal to 2 for all access categories (AC) of non access point stations and greater or equal to one for access points. If we assume that the AIFSN for the access point is one and for three of the access categories 2,3 and 4, then in the worst case the difference of the time needed by HCCA and EDCA is 3slotTimes + CW[3] <> CFPoll+ SIFS. Within a congested channel with low service interval values, which is the case with the above defined service interval selection criteria, it is not trivial to assume that the 'next' access category that is going to send its packets has a backoff timer of length 1 time slot. Considering this, 4slotTimes < CFPoll + SIFS will be true for most of the usual configurations of the parameters of 802.11e. One could argue the fact that CFPoll can be piggybacked on a QoS DATA frame so that the QAP does not have to wait extra AIFS long. However, in such cases the physical transmission rate of QoS DATA frame is reduced to a basic rate, which is the smallest of the maximum physical transmission rates of all the associated stations. If there is one station away from the QAP or a station using 802.11b instead of 802.11g, this would increase the time needed for sending QoS DATA even further. For this reason, piggybacking is not a solution to the mentioned problem. Hence it makes sense not to reserve time during HCCA for uplink traffic. This is true even if the time needed by HCCA is shorter than the time needed by EDCA, since there is an upper bound for the time reserved to HCCA. In a crowded network reserving time for uplink traffic within HCCA degrades the performance of downlink traffic because there is not enough time to reserve TXOPs to all downlink streams. Additionally reserving more TXOPs in the HCCA scheduler results losing more time during a service interval as explained in the previous section. We can reduce this lost time by distributing less TXOPs to the uplink traffic.

An exception to this argument is the bidirectional traffic. If the traffic is bidirectional, it makes no sense to keep the QoS of one direction good, ignoring the other. Therefore the number of bidirectional streams should be optimized regarding both directions. Consequently there must be a balance between HCCA and EDCA for bidirectional traffic. Access point must make sure that expected time in EDCA is sufficient for the packets of the bidirectional traffic which are not being served within HCCA.

To summarize:

- Reserve time of HCCA first of all for downlink traffic.
- Even if there is remaining time in the HCCA scheduler, we are better off if we do not reserve TXOPs for uplink traffic in case there is a high congestion probability. This is true as long as we do not have strict service level agreements for such traffic.
- It does not make sense to reserve time for bidirectional traffic in case the requirements of one direction cannot be fulfilled.

Taking these into account, we developed an admission control mechanism which consists of following constraints:

$$\sum_{j=1}^{3}\sum_{i=1}^{j}((\frac{a_{j,i}*(1+b_{j,i})*SI}{s_{j,i}}-x_{j,i})*q_{j,i})+\sum_{j=1}^{3}\sum_{i=1}^{j}x_{j,i}*p_{j,i}+B\leq SI, \tag{13}$$

$$a_{j,i}\geq x_{j,i}, \tag{14}$$

$$\sum_{j=1}^{3}\sum_{i=1}^{j}x_{j,i}*p_{j,i}\leq HCCAlimit, \tag{15}$$

$$x_{j,i}\,\epsilon\,downlink, \tag{16}$$

$$a_{j,i} \,\epsilon 0, 1, \tag{17}$$

where k is the number of streams in the scheduler, $b_{j,i}$ is the binary for bidirectional traffic and $a_{j,i}$ determines if the stream is accepted by the HCCA scheduler or not. Constraints (13) and (14) make sure that bidirectional streams receive TXOPs for uplink and downlink in case they are accepted and the total amount of time reserved for HCCA TXOPs plus the time used by uncontrolled traffic is smaller than the selected service interval. Constraint (15) makes sure that the time reserved for HCCA is less than the maximum amount of time allowed and last constraint reserves HCCA TXOPs only to downlink traffic. If the incoming streams satisfy all the above defined constraints, then they are accepted to the HCCA scheduler. This admission control mechanism is used within our simulation runs in the following section.

6 Simulation

6.1 Simulation Environment

In order to show the effect of the service interval choice in different traffic situations we run simulations using an updated and slightly corrected version of ns2 network simulator for 802.11e developed by [14]. Within the simulation environment, there is one access point and different number of stations of each priority. Each station uses only one type of traffic. There are a total of 6 types of traffic during simulations. These are given as follows:

1. First priority, bidirectional constant bit rate (CBR) traffic using UDP with a packet size of 160 bytes and sample intervals (interarrival rate) of 5,8,10,15,..,35 ms. (1^{st} access category)
2. First priority, bidirectional constant bit rate (CBR) traffic using UDP with a constant voice payload of 64 Kbps and interarrival rate of 10,20 and 30 ms. (1^{st} access category)
3. First priority, bidirectional constant bit rate (CBR) traffic using UDP with a constant voice payload of 8 Kbps and interarrival rates of 10,20, 30 ms. (1^{st} access category)
4. Second priority CBR traffic using UDP with a packet size 1280 bytes and interarrival rate of 5, 10, 20, 30ms.(2^{nd} access category)
5. Bidirectional interactive traffic using TCP with a packet size of 1100 bytes and exponentially distributed arrival rates having an average of 50ms on time, 30ms off time and sending rate of 60Kbits/s during on times corresponding to an average of 10Kbytes/s. This complies with the interactive traffic definition of 3GPP TS 22.105 [15] and ITU G.1010 [16]. (3^{rd} access category)
6. VBR Background traffic using TCP with a packet size of 1200 bytes and exponentially distributed inter arrival times having an average of 1000ms off and 200ms on times with a sending rate of 100Kbits/s corresponding to low load 11Kbytes/s traffic. (4^{th} access category)

The first three traffic types are defined to simulate voice traffic. The first traffic type targets at showing the effects of changing interarrival rates without caring for the existence of a corresponding voice codec being used in the internet. The second and third types represent the codecs G.711 and G.729 correspondingly as defined in Cisco Call Manager [17]. These three types of voice packets cover most of the used codec formats in the internet [18]. The second priority is defined for video traffic with different qualities which also comprises most of the video codecs being used in the internet [19]. Third and fourth traffic types are defined to simulate normal hot spot user behaviour as given in [20]. As a result, the results presented in the following sections are representative for most of the traffic combinations being used currently. Additionally the 802.11e specific parameters are given in table 1.

Table 1. List of Simulation Parameters

Bandwidth	11Mbps
PLCPTransmissionrate	1 Mbps
RTSThreshold	$3000\mu s$
ShortRetryLimit	7
LongRetryLimit	4
slotTime	$9\mu s$
AIFS(1,2,3,4)	$1, 2, 6, 12$
CWmin(1,2,3,4)	$7, 15, 15, 31$
CWMax(1,2,3,4)	$15, 31, 255, 525$

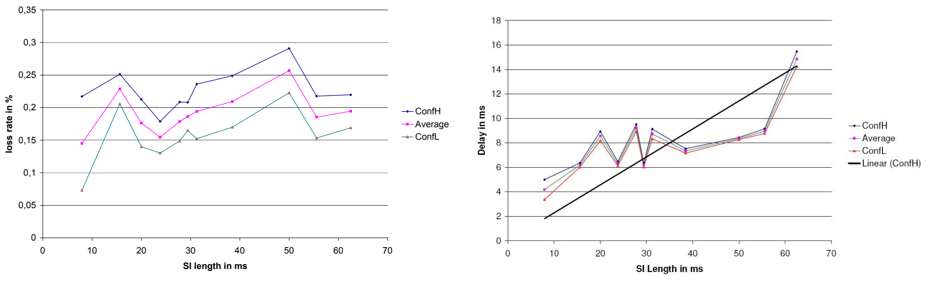
6.2 Simulation Results

The results presented in this section are the average results where we used up to 13 background, 13 interactive, 5 video and 14 voice streams with a changing ratio of the maximum amount of time reserved to HCCA (from 14% to 82%). In each run, voice streams are selected from the defined three types of first priority traffic randomly. In case not otherwise stated, the largest 99% confidence interval is within 20% of the given results. For each service interval and voice stream count combination we evaluated 4225 runs.

The results of our simulations mostly coincide with the findings presented in the previous section. As seen in Fig. 6(a), choosing different service intervals has no effect on the packet loss rate of high priority traffic. The differences between the loss rates at different service intervals are either statistically insignificant or ignorably small. We also observe an increasing delay for high priority traffic in SI as shown in Fig. 6(b). However the experienced average delay during our simulations is less than the theoretical delay which is nearly equal to the half of the service interval. A linear regression of the simulation results gives a slope of 0.22 with an R^2 value of 0.24. The R^2 value shows the goodness of fit and is calculated as:

$$R^2 = 1 - \frac{SSE}{SST} \tag{18}$$

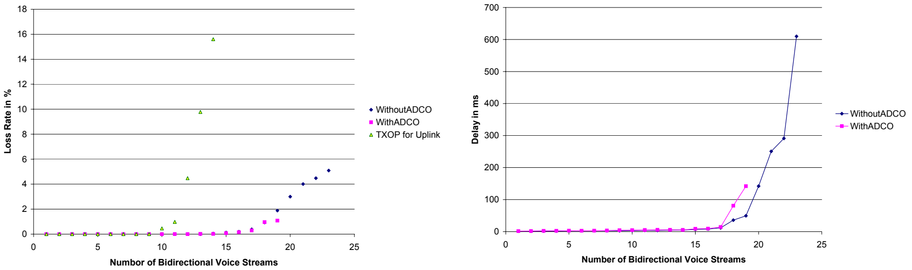
where SSE is the sum squared error and SST is the total variance in the data. As R^2 approaches 1 the regression approaches a perfect fit. The fit is not perfect in our case, since we also used service intervals which are multiples of the interarrival rates. This introduces a deviation to the expected delay. Additionally, we could not show that choosing a common multiple of the interarrival rates as the service interval length decreases the average delay as explained in section 4. In fact with service intervals 25ms, 30ms and 40ms this effect is observable. However this is not true for service interval values 20ms and 50ms. This may be due to some minor implementation errors in the network simulator ns2.



(a) (b)

Fig. 6. Effect of service interval choice on delay and loss rate. ConfH and ConfL illustrate the 99% confidence interval levels

On the other hand simulation runs in which we used an admission control mechanism by implementing the findings of the previous section proved to be very efficient in terms of channel reservation. As seen from Fig. 7(a), if we distribute TXOPs to the uplink traffic, then unacceptable loss rates occur starting with the 12^{th} bidirectional voice stream. However this number grows up to 18 if only downlink traffic receives TXOPs. On the other hand using the admission control mechanism which combines the findings of the previous section does not allow more than 19 voice streams. For the 19^{th} stream the service interval is increased using equation (9)and the effect of this increment can be seen in Fig. 7(a) where the loss rate is about the half of the case without the admission control mechanism. However this happens at the cost of more delay as seen in Fig. 7(b). As seen, the admission control algorithm does not allow delay more than 150ms.



(a) (b)

Fig. 7. Comparison of delay and loss rates of 1^{st} priority traffic with different admission control mechanisms

7 Conclusion

Research activities on the upcoming standard 802.11e show that WLAN will be able to satisfy high QoS expectations of different applications much more than we can reach currently. 802.11e does this by offering both diffserv and intserv mechanisms at the same time in a comprehensive manner. However only an efficient cooperation of these two mechanisms makes sure that the resultant QoS levels are as high as expected.

In this paper we studied the effects of the service interval on the delay and loss rate of high priority traffic. We showed that, with a clever choice of the service interval it is possible to reach much higher QoS levels. Using these results we suggested very simple changes in the recommended way of calculating service intervals. We also divided the traffic into four categories as uplink, downlink, bidirectional and unidirectional traffic and assigned these traffic categories into HCCA and EDCA based on their transmission procedures. We showed using simulation analysis that the suggested methods enable an efficient cooperation of EDCA and HCCA by maximizing the numbers of streams that can be offered for higher priority streams and keeping the QoS within acceptable limits.

We are currently working on developing novel ways for making autonomous decisions by the hybrid coordinator so that the usage of EDCA and HCCA are optimized dynamically without being dependent on the scheduling algorithms used by different vendors.

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