IEEE 802.11e Wireless LAN for Quality of Service

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ABSTRACT

In this paper, a comprehensive overview of the new features of an upcoming new standard IEEE 802.11e to support Quality of Service (QoS) in Wireless Local Area Networks (WLANs) is presented. We address Medium Access Control (MAC) enhancements found in the current 802.11e draft specification by emphasizing the differences from the legacy 802.11 standard. New mechanisms for QoS support, namely Enhanced Distributed Coordination Function (EDCF) and Hybrid Coordination Function (HCF), defined in the 802.11e draft are evaluated. The performance of those new schemes is discussed via simulation results

LIST OF ABBREVIATIONS

ACK	*Acknowledgement*	
AIFS	*Arbitration Inter Frame Space*	*(802.11e)*
AP	*Access Point*	
CA	*Collision Avoidance*	
CDF	*Complementary Cumulative Distribution Function*	
CFP	*Contention Free Period*	
CF-Poll	*Contention Free – Poll*	
CF-End	*Contention Free – End*	
CP	*Contention Period*	
CSMA	*Carrier Sense Multiple Access*	
CW	*Contention Window*	
CWmax	*Contention Window Maximum*	
CWmin	*Contention Window Minimum*	
DCF	*Distributed Coordination Function*	
EDCF	*Enhanced DCF*	*(802.11e)*
HC	*Hybrid Coordinator*	*(802.11e)*
HCF	*Hybrid Coordination Function*	*(802.11e)*
IEEE	*Institute of Electrical and Electronics Engineers*	
ISM	*Industrial, Science, Medical*	
LRE	*Limited Relative Error*	
MAC	*Medium Access Control*	
MSDU	*MAC Service Data Unit*	
NAV	*Network Allocation Vector*	
PC	*Point Coordinator*	
PCF	*Point Coordination Function*	
PF	*Persistence Factor*	*(802.11e)*
PHY mode	*Physical Layer mode, coding and modulation scheme*	
PIFS	*PCF Inter Frame Space*	
(Q)BSS	*(QoS-supporting) Basic Service Set*	*(802.11e)*
QoS	*Quality of Service*	
RTS/CTS	*Request to Send/Clear to Send*	
SIFS	*Short Inter Frame Space*	
TBTT	*Target Beacon Transmission Time*	
TC	*Traffic Category*	*(802.11e)*
TXOP	*Transmission Opportunity*	*(802.11e)*
WLAN	*Wireless Local Area Network*	

1. INTRODUCTION

IEEE 802.11 (*802.11*) WLAN standard is being accepted widely and rapidly for many different environments today [1]. Main characteristics of the 802.11 networks are their simplicity and robustness against failures due to the distributed approach. Using the ISM band at *2.4 GHz*, the 802.11b version provides data rates of up to *11 Mbit/s* at the wireless medium. Now, the new 802.11a version can achieve data rates of up to *54 Mbit/s* at the wireless medium using the OFDM modulation technique in the unlicensed *5 GHz* band [4]. Today, 802.11 WLAN can be considered as a wireless version of Ethernet, which supports best-effort service. However, the interest in wireless networks supporting QoS has recently grown [1]-[8]. Accordingly, the 802.11 Working Group established an activity to enhance the current 802.11 MAC protocol to support applications with QoS requirements. The concepts described in this paper are in line with the standardization efforts of Philips to enhance the QoS functionality of WLANs. Such a network could open a variety of opportunities for new multimedia applications on mobile/portable devices.

In this paper, we discuss the enhancements of the 802.11e supplement standard as they are specified in the latest draft [11], to compare them to the legacy 802.11 standard [9], and to characterize their efficiency. In Section 2, the limitations of the QoS support in the legacy 802.11 are discussed. Section 3 summarizes the new mechanisms for QoS support, which are being defined by 802.11e. A performance evaluation of the described mechanisms through simulation results is presented in Section 4. The paper concludes with a summary in Section 5.

2. LEGACY 802.11

Here we briefly summarize the 802.11 MAC protocol and discuss its limitations in QoS support. We consider an infrastructure Basic Service Set (*BSS*) of IEEE 802.11 WLAN, which is composed of an Access Point (*AP*) and a number of stations associated with the AP. The AP connects its stations with the infrastructure.

2.1 Distributed Coordination Function

The basic 802.11 MAC protocol is the Distributed Coordination Function (*DCF*) that works as listen-before-talk scheme, based on the Carrier Sense Multiple Access (*CSMA*). Stations deliver MAC Service Data Units (*MSDUs*) of arbitrary lengths (up to *2304 bytes*), after detecting that there is no other transmission in progress on the wireless medium. However, if two stations detect the channel as free at the same time, a collision occurs. The 802.11 defines a Collision Avoidance (*CA*) mechanism to reduce the probability of such collisions. As part of CA, before starting a transmission a station performs a backoff procedure. It has to keep sensing the channel for an additional random time after detecting the channel as being idle for a minimum duration called DCF Interframe Space (*DIFS*), which is *34 us* for 802.11a. Only if the channel remains idle for this additional random time period, the station is allowed to initiate the transmission. The duration of this random time is determined as a multiple of a slot time (*9 us* in 802.11a). Each station maintains a so-called Contention Window (*CW*), which is used to determine the number of slot times a station has to wait before transmission.

For each successful reception of a frame, the receiving station immediately acknowledges the frame reception by sending an acknowledgement frame (*ACK*). The CW size increases when a transmission fails, i.e., the transmitted data frame has not been acknowledged. After any unsuccessful transmission attempt, another backoff is performed with a doubled size of the CW. This reduces the collision probability in case there are multiple stations attempting to access the channel. The stations that deferred from channel access during the channel busy period do not select a new random backoff time, but continue to count down the time of the deferred backoff in progress after sensing a channel as being idle again. In this manner, stations, that deferred from channel access because their random backoff time was larger than the backoff time of other stations, are given a higher priority when they resume the transmission attempt. After each successful transmission, another random backoff is performed by the transmission-completing station, even if there is no other pending MSDU to be delivered. This is called "post-backoff", as this backoff is done after, not before, a transmission.

There is one situation when a station is not required to perform the random backoff before starting data transmission. An MSDU arriving at the station from the higher layer may be transmitted immediately without waiting any time, if the last post-backoff has been finished already, i.e., the queue was empty, and additionally the channel has been idle for a minimum duration of DIFS. All the following MSDUs after this MSDU have to be transmitted after random backoff, until the transmission queue is empty again. To limit the probability of long frames colliding and being transmitted more than once, data frames may also be fragmented. Via fragmentation a large MSDU can be divided into several smaller data frames, i.e., fragments, which can then be transmitted sequentially as individually acknowledged data frames. The benefit of fragmentation is, in case of failed transmission, that the error is detected earlier and there is less data to re-transmit. The obvious drawback is the increased overhead.

To reduce the hidden station problem inherent in CSMA, 802.11 defines a Request-to-Send/Clear-to-Send (*RTS/CTS*) mechanism, which can be used optionally. Before transmitting data frames, a station has the option to transmit a short RTS frame, followed by the CTS transmission by the receiving station. The RTS and CTS frames include the information of how long it does take to transmit the next data frame, i.e., the first fragment, and the corresponding ACK response. Thus, other stations close to the transmitting station and hidden stations close to the receiving station will not start any transmissions; their timer called Network Allocation Vector, *NAV,* is set. RTS/CTS helps to protect long data frames against hidden stations. With fragmentation, multiple ACKs are transmitted, whereas with RTS/CTS the MSDU can be efficiently transmitted in a single data frame. Between two consecutive frames in the sequence of RTS, CTS, data, and ACK frames, a Short Interframe Space (*SIFS*), which is *16 us* for 802.11a, gives transceivers time to turn around. See Fig. 1 for an example of the DCF. It is important to note that SIFS is shorter than DIFS, which gives CTS responds and ACKs always the highest priority for access to the wireless medium.

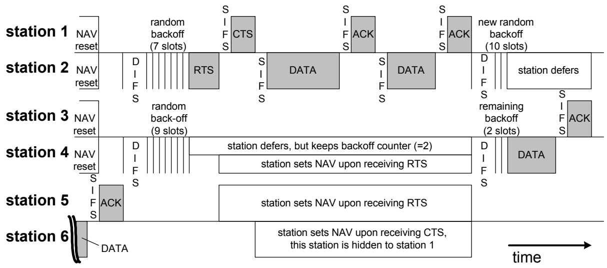

Fig. 1: Timing of the 802.11 DCF. In this example, station 6 cannot detect the RTS frame of the transmitting station 2, but the CTS frame of station 1.

2.2 Limited QoS support with Point Coordination Function

To support time-bounded services, the IEEE 802.11 standard defines the Point Coordination Function (*PCF*) to let stations have priority access to the wireless medium, coordinated by a station called Point Coordinator (*PC*). The PCF has higher priority than the DCF, because it may start transmissions after a shorter duration than DIFS; this time space is called PCF Interframe Space (*PIFS*), which is *25 us* for 802.11a and longer than SIFS, i.e., the shortest inter-frame-space. Time is always divided into repeated periods, called *superframes*. With PCF, a Contention Free Period (*CFP*) and a Contention Period (*CP*) alternate over time, in which a CFP and the following CP form a *superframe*. During the CFP, the PCF is used for accessing the medium, while the DCF is used during the CP. It is mandatory that a superframe includes a CP of a minimum length that allows at least one MSDU Delivery under DCF.

A superframe starts with a so-called beacon frame, regardless if PCF is active or not. The beacon frame is a management frame that maintains the synchronization of the local timers in the stations and delivers protocol related parameters. The PC, which is typically co-located with the AP, generates beacon frames at regular beacon frame intervals, thus every station knows when the next beacon frame will arrive; this time is called target beacon transition time (*TBTT*) and is announced in every beacon frame. Note that the beacon frame is required in pure DCF even if there is only contending traffic. There is no contention between stations; rather, stations are polled. See Fig. 2 for a typical sequence during CFP. The PC polls a station asking for a pending frame. Because the PC itself has pending data for this station, it uses a combined date and poll frame by piggybacking the *CF-Poll* frame on the data frame.

Upon being polled, along with data, the polled station acknowledges the successful reception. If the PC received no response from a polled station after waiting for PIFS, it polls the next station, or ends the CFP. Thus no idle period longer than PIFS occurs during CFP. The PC continues with polling other stations until the CFP expires. A specific control frame, called CF-End, is transmitted by the PC as the last frame within the CFP to signal the end of the CFP.

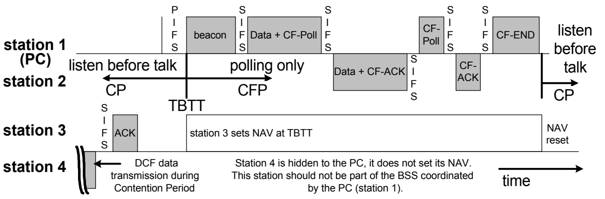

Fig. 2: Example for the PCF operation. Station 1 is the PC polling station 2. Station 3 detects the beacon frame and sets the NAV for the whole CFP. Station 4 is hidden to station 1 and does not detect the beacon frame; it continues to operate in DCF.

There are problems with the PCF that led to the current activities to enhance the protocol. Among many others, those include the unpredictable beacon delays and unknown transmission durations of the polled stations. At TBTT, a PC schedules the beacon as the next frame to be transmitted, and the beacon can be transmitted when the medium has been determined to be idle for at least PIFS. Depending on the wireless medium at this point of time, i.e., whether it is idle or busy around the TBTT, a delay of the beacon frame may occur. The time the beacon frame is delayed, i.e., the duration it is sent after the TBTT, delays the transmission of time-bounded MSDUs that have to be delivered in CFP. From the legacy 802.11 standard, stations can start their transmissions even if the MSDU Delivery cannot finish before the upcoming TBTT [9]. This may severely affect the QoS as this introduces unpredictable time delays in each CFP. Beacon frame delays of around *4.9 ms* are possible in 802.11a in the worst case. In simulations of the PCF we performed, mean beacon frame delays of up to *250 us* occurred, depending on frame lengths, fragmentation, and the offered traffic, as illustrated in Fig. 3.

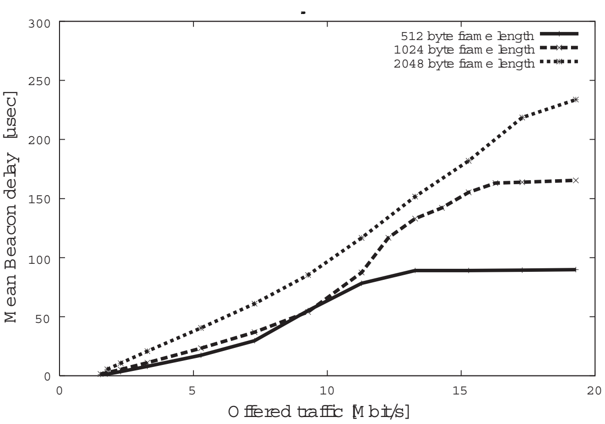

Fig. 3: Simulated mean beacon frame delay in legacy 802.11a. A legacy station stops all timers at TBTT and therefore does not initiate a transmission after TBTT. However, it continues on-going transmissions that started before TBTT, and hence beacon frames may be delayed.

There is another problem with the PCF, the unknown transmission time of polled stations. A station that has been polled by the PC is allowed to send a single frame that may be fragmented and of arbitrary length, up to the maximum of *2304 bytes* (*2312 bytes* with encryption). Further, different modulation and coding schemes are specified in 802.11a, thus the duration of the MSDU Delivery that happens after polling is not under the control of the PC. This destroys any attempt to provide QoS to other stations that are polled during the rest of the CFP.

A hidden station that misses the previous beacon frames and does not have any knowledge about the TBTT does not stop its operation based on DCF. It is likely that it transmits interfering frames during CFP. In general, a station sets the NAV at TBTT irrespective of the reception of a beacon frame. However, if it did not receive any of the beacon frames before, it does not set the NAV at TBTT.

3. QOS SUPPORT MECHANISMS OF 802.11E

To support QoS, there are priority schemes currently under discussion [11]. IEEE 802.11 Task Group E currently defines enhancements to the above-described 802.11 MAC, called 802.11e, which introduces EDCF and HCF. Stations, which operate under 802.11e, are called enhanced stations, and an enhanced station, which may optionally work as the centralized controller for all other stations within the same QBSS, is called the Hybrid Coordinator (*HC*). A QBSS is a BSS, which includes an 802.11e-compliant HC and stations. The HC will typically reside within an 802.11e AP. In the following, we mean 802.11e-compliant enhanced stations by stations.

With 802.11e, there may still be the two phases of operation within the superframes, i.e., a CP and a CFP, which alternate over time continuously. The EDCF is used in the CP only, while the HCF is used in both phases, which makes this new coordination function hybrid.

3.1 Enhanced Distributed Coordination Function

The EDCF in 802.11e is the basis for the HCF. The QoS support is realized with the introduction of Traffic Categories (*TCs*). MSDUs are now delivered through multiple backoff instances within one station, each backoff instance parameterized with TC-specific parameters. In the CP, each TC within the stations contends for a TXOP and independently starts a backoff after detecting the channel being idle for an Arbitration Interframe Space (*AIFS*); the AIFS is at least DIFS, and can be enlarged individually for each TC. After waiting for AIFS, each backoff sets a counter to a random number drawn from the interval [*1,CW+1*]. The minimum size (*CWmin[TC]*) of the CW is another parameter dependent on the TC. Priority over legacy stations is provided by setting *CWmin[TC]<15* (in case of 802.11a PHY) and *AIFS=DIFS*. See Fig. 4 for illustration of the EDCF parameters.

As in legacy DCF, when the medium is determined busy before the counter reaches zero, the backoff has to wait for the medium being idle for AIFS again, before continuing to count down the counter. A big difference from the legacy DCF is that when the medium is determined as being idle for the period of AIFS, the backoff counter is reduced by one beginning the last slot interval of the AIFS period. Note that with the legacy DCF, the backoff counter is reduced by one beginning the first slot interval after the DIFS period. After any unsuccessful transmission attempt a new CW is calculated with the help of the persistence factor *PF[TC]* and another uniformly distributed backoff counter out of this new, enlarged CW is drawn, to reduce the probability of a new collision. Whereas in legacy 802.11 CW is always doubled after any unsuccessful transmission (equivalent to *PF=2*), 802.11e uses the PF to increase the CW different for each TC:

$$newCW[TC] >= ((oldCW[TC]+1)*PF)-1$$

The CW never exceeds the parameter *CWmax[TC]*, which is the maximum possible value for CW.

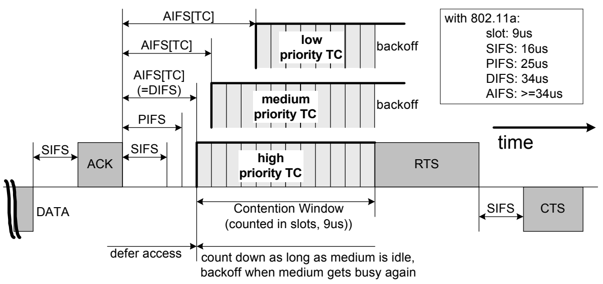

Fig. 4: Multiple backoff of MSDU streams with different priorities.

A single station may implement up to eight transmission queues realized as virtual stations inside a station, with QoS parameters that determine their priorities. If the counters of two or more parallel TCs in a single station reach zero at the same time, a scheduler inside the station avoids the *virtual collision*. The scheduler grants the TXOP to the TC with highest priority, out of the TCs that virtually collided within the station, as illustrated in Fig. 5. There is then still a possibility that the transmitted frame collides at the wireless medium with a frame transmitted by other stations.

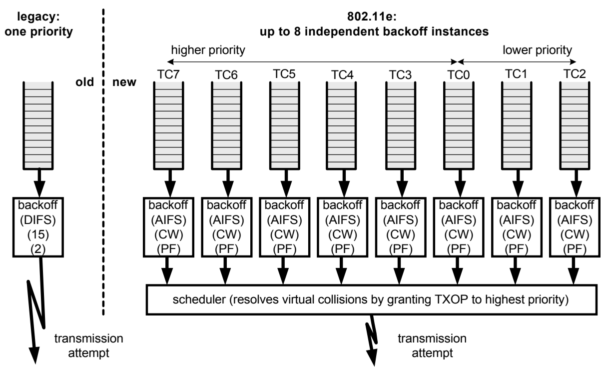

Fig. 5: Virtual backoff of eight traffic categories: (1) left one: legacy DCF, close to EDCF with AIFS=34us, CWmin=15, PF=2; (2) right one: EDCF with AIFS[TC]>=34us, CWmin[TC]=0-255, PF[TC]=1-16.

One crucial feature of 802.11e MAC is the Transmission Opportunity (*TXOP*). A TXOP is defined as an interval of time when a station has the right to initiate transmissions, defined by a starting time and a maximum duration. TXOPs are allocated via contention (*EDCF-TXOP*) or granted through HCF (*polled-TXOP*). The duration of an EDCF-TXOP is limited by a QBSS-wide TXOP limit distributed in beacon frames, while the duration of a polled TXOP is specified by the duration field inside the poll frame. However, although the poll frame is a new frame as part of the upcoming 802.11e, also the legacy stations set their NAVs upon receiving this frame. More details about polled TXOP follow in the next subsection. The prioritized channel access is realized with the QoS parameters per TC, which include AIFS[TC], CWmin[TC], and PF[TC]. CWmax[TC] is optional. Discussions are ongoing to introduce a priority dependent EDCF-TXOP[TC]. The QoS parameters can be adapted over time by the HC, and will be announced periodically via the beacon frames. Protocol-related parameters are included in the beacon frame, which is transmitted at the beginning of each superframe.

3.2 Hybrid Coordination Function

The HCF extends the EDCF access rules. The HC may allocate TXOPs to itself to initiate MSDU Deliveries whenever it wants, however, only after detecting the channel as being idle for PIFS, which is shorter than DIFS. To give the HC priority over the EDCF, AIFS must be longer than PIFS and can therefore not have a value smaller than DIFS.

During CP, each TXOP begins either when the medium is determined to be available under the EDCF rules, i.e., after AIFS plus backoff time, or when the station receives a special poll frame, the QoS CF-Poll, from the HC. The QoS CF-Poll from the HC can be sent after a PIFS idle period without any backoff. Therefore the HC can issue polled TXOPs in the CP using its prioritized medium access. During the CFP, the starting time and maximum duration of each TXOP is specified by the HC, again using the QoS CF-Poll frames. Stations will not attempt to get medium access on its own during the CFP, so only the HC can grant TXOPs by sending QoS CF-Poll frames. The CFP ends after the time announced in the beacon frame or by a CF-End frame from the HC. See Fig. 6 for an example of an 802.11e superframe.

As part of 802.11e, an additional random access protocol that allows fast collision resolution is defined. The HC polls stations for MSDU Delivery. For this, the HC requires information that has to be updated by the polled stations from time to time. Controlled contention is a way for the HC to learn which station needs to be polled, at which times, and for which duration. The controlled contention mechanism allows stations to request the allocation of polled TXOPs by sending resource requests, without contending with other (E)DCF traffic. Each instance of controlled contention occurs during the controlled contention interval, which is started when the HC sends a specific control frame. This control frame forces legacy stations to set their NAV until the end of the controlled contention interval, thus they remain silent during the controlled contention interval. The control frame defines a number of controlled contention opportunities (i.e., short intervals

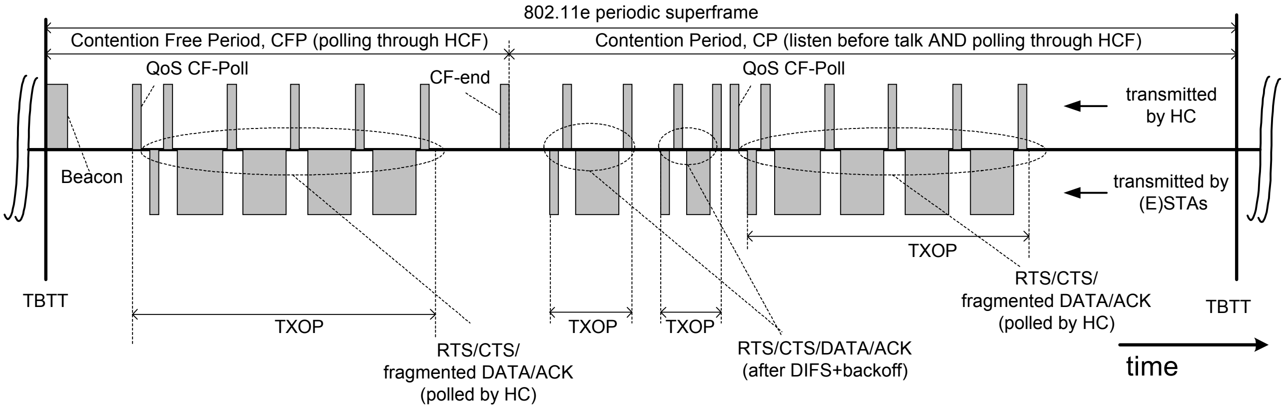

Fig. 6: A typical 802.11e superframe. The concept relies on TXOPs. Polled-TXOPs may be located in CP and CFP.

separated by SIFS) and a filtering mask containing the TCs in which resource requests may be placed. Each station with queued traffic for a TC matching the filtering mask chooses one opportunity interval and transmits a resource request frame containing the requested TC and TXOP duration, or the queue size of the requested TC. For fast collision resolution, the HC acknowledges the reception of request by generating a control frame with a feedback field so that the requesting stations can detect collisions during controlled contention.

4. EVALUATION

We use event-driven stochastic simulations to evaluate the performance of 802.11e EDCF and HCF for the 802.11a physical layer at 5GHz that allows up to *54 Mbit/s*. For the delay results, we give empirical Complementary Cumulative Distribution Functions (*CDFs*) of the resulting stochastic data, using the discrete Limited-Relative-Error (*LRE*) algorithm that also measures the local correlation of the stochastic data [11]. By measuring local correlations, the accuracy of empirical simulation results can be estimated. All results here are within a maximum limited relative error of *5 %*.

The following evaluation contains:

- scenario description
- achievable EDCF-throughput in the scenario
- QoS support with EDCF
- QoS support with EDCF contending with DCF
- QoS guarantees with HCF

4.1 Scenarios

Five stations form a QBSS with one station being the AP. This AP either implements the EDCF or the HCF, the four other stations operate in EDCF. In some scenarios, two QBSSs are co-located to each other, as illustrated in Fig. 7, so that they interfere to each other. To investigate the performance of 802.11e in hot spots, we also vary the number of stations in a QBSS, each station offering the same traffic, and measure the throughput per traffic category, see Fig. 8.

In all simulations, a radio channel error model as described in [4],[5] is used. Transmission powers and distances between stations are chosen in such a way that they are not hidden to each other with the selected PHY modes. If not stated otherwise, all frames but the data frames are transmitted with *6 Mbit/s* PHY mode. Data frames are transmitted with *24 Mbit/s* PHY mode. Each station generates the same mix of offered traffic of three data streams, which we label with high, medium and low, according to their priorities. At the high priority TC, MSDUs of *80 bytes* arrive at the constant periods. The period depends on the offered traffic and is *5 ms* for the offered traffic of *128 kbit/s*. The medium and low priority TCs are each offered MSDUs of *200 bytes* with Poisson inter-arrival times, each stream with *160 kbit/s*. The following Table 1 shows the EDCF-parameters selected for the three priorities, summarizing the EDCF parameters we mainly use.

Table 1: Used EDCF parameters for the three TCs.

	High	Medium	Low
AIFS*	*2*	*4*	*7*
CWmin	*7*	*10*	*15*
CWmax	*7*	*31*	*255*
PF	*2*	*2*	*2*

*) When AIFS is represented by a number instead of time, the actual AIFS in time is determined by SIFS (which is *16 us* in 802.11a) + AIFS (in number) * slot_time (which is *9 us* in 802.11a).

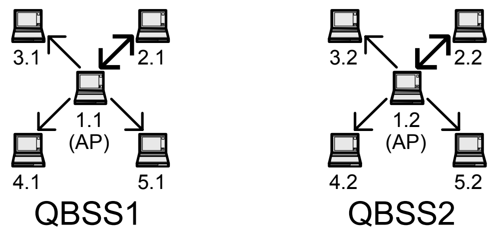

Fig. 7: Scenario with two QBSSs.

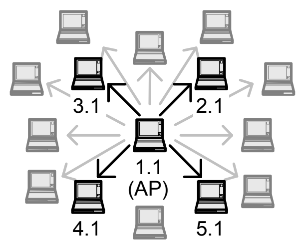

Fig. 8: One AP with variable number of stations. All stations are within the range of each other.

If not stated otherwise, during simulation neither RTS/CTS nor fragmentation is used. The fragmentation threshold is set to *256 bytes*. The duration of EDCF-TXOPs allows stations to transmit one data frame after winning the contention in EDCF. In all scenarios the AP transmits beacon frames once every *102.4 ms*.

4.2 Maximum achievable throughput in EDCF

The maximum achievable throughput depends on a large number of parameters. The results given here are valid for the MAC and PHY settings we use in our simulation. Table 2 is derived from a simulation with a single station transmitting one stream of a single priority, to assess the maximum achievable throughput under EDCF in our scenarios.

As it is well known, the throughput in 802.11 depends very much on the size of the data frames. That is, the larger frame size, the higher the achievable throughput. We also observe that a higher priority stream achieves a higher throughput thanks to smaller AIFS, CWmin, and CWmax values.

Table 2: Maximum achievable throughput for the 3 TCs.

data frame size	80 bytes	200 bytes	2304 bytes
High	*3.5 Mbit/s*	*not used*	*19.81 Mbit/s*
Medium	*not used*	*6.22 Mbit/s*	*19.16 Mbit/s*
Low	*not used*	*5.21 Mbit/s*	*18.22 Mbit/s*

4.3 QoS support with EDCF

As there is no central coordination in EDCF, QoS-support is reached by varying the probability of winning an instance of TXOP in contention. In EDCF, support of QoS can be achieved statistically by reducing the probability of medium access for lower priority TCs. An isolated QBSS with five stations and three streams each results in MSDU Delivery delays as shown in Fig. 9. The MSDU Delivery delay includes the transmission time, therefore the minimum delay depends on the data frame length. Note that the minimum delay does not include the AIFS, nor does it include the backoff calculated with the CW.

To show the priorities in terms of throughput, we increase the number of contending stations, as indicated in Fig. 8. The Fig. 10 shows the resulting throughputs for the three priorities. The low priority streams cannot carry their traffic for more than ten contending stations. Whereas the high priority streams always carry their traffic completely, the medium priority throughput decreases for thirteen or more contending stations.

It is difficult to find the right EDCF parameters. A first approach could be to have non-overlapping CWs for the different priorities. In Fig. 11 the resulting throughput of such a parameter selection is given for the isolated QBSS with five stations. Here, we set *AIFS[High]=2*, *AIFS[Medium]=10,* and *AIFS[Low]=18*. With *CWmin=CWmax=7* for all priorities, contention among TCs of different priorities does not occur. Contention occurs among TCs of the same priority from different stations only. A backoff instance of certain priority wins the contention only if there is no other backoff instance of higher priority attempting to transmit.

In our scenario, the traffic load is increased by increasing the offer per medium priority stream, not by increasing the number of stations. Meanwhile, the offer per high and low priority streams keeps constant at the known levels. With non-overlapping CW, an undesirable drop of throughput for the low priority stream happens. As soon as the medium priority streams always attempts to transmit data frames, the low priority throughput drops to zero. When setting EDCF parameters in 802.11e, it should be taken into account that non-overlapping CWs lead to very strict priorities.

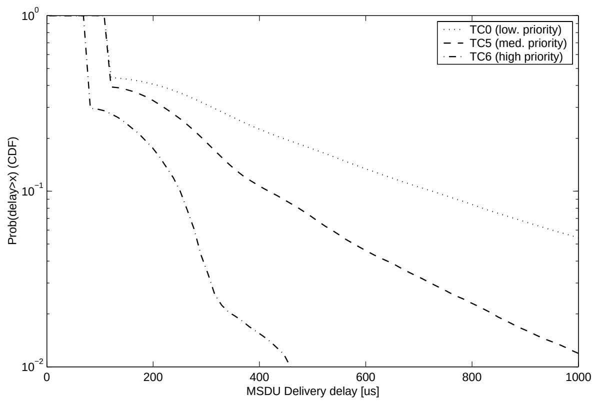

Fig. 9: EDCF MSDU Delivery delays in an isolated QBSS with five stations.

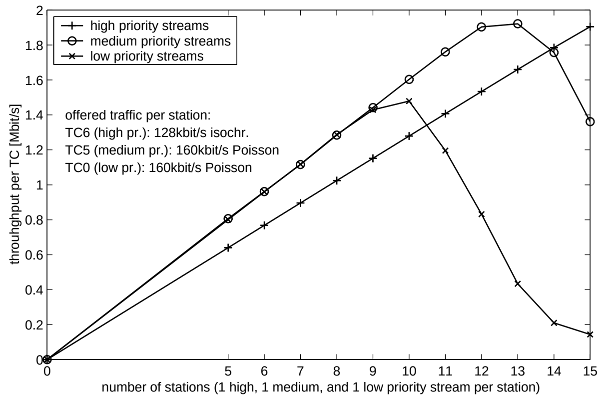

Fig. 10: Throughput vs. offered traffic. The throughput increases with the offer at the cost of streams with the lower priority.

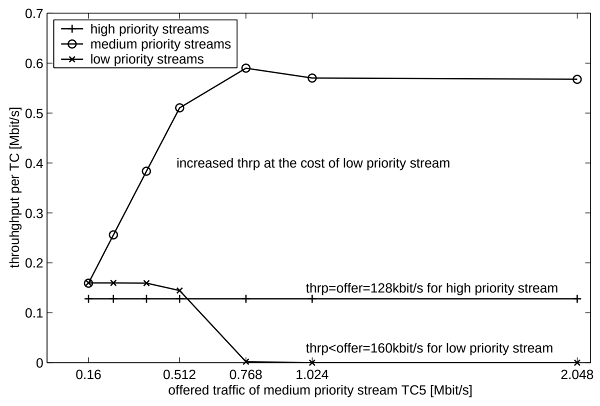

Fig. 11: Throughput vs. offered traffic with non-overlapping CWs. The low priority throughput decreases dramatically with increasing medium priority offer. Simulation of an isolated QBSS with five stations.

4.4 QoS support with EDCF contending with DCF

As discussed before, AIFS cannot be smaller than DIFS. Thus, the question arises if EDCF stations do really have a chance to have higher priority than legacy stations. In the scenario shown in Fig. 12, the variation of AIFS, CWmin, CWmax and PF of one transmitting enhanced station in comparison to one transmitting legacy station is evaluated. Results are given in Fig. 13, which shows two figures with resulting throughputs for different settings of the EDCF parameters.

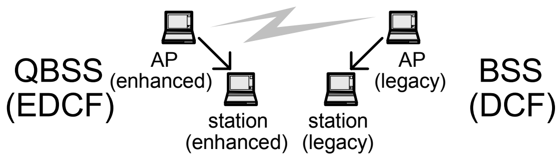

Fig. 12: Scenario of contending DCF and EDCF stations. One stream per transmitting station, the stations always attempt to transmit.

In the top figure, AIFS is set to *AIFS=DIFS+4 slots*; the other QoS parameters (CWmin, CWmax, PF) are varied in the five indicated simulations. It can be seen that with a very small CWmin, the enhanced station does have priority access. Reducing CWmin is the significant mean to prioritize an enhanced station over legacy stations for such a small number of contending stations. The bottom figure indicates that due to the changed backoff counter decrements in EDCF, even with *AIFS=DIFS* the enhanced station has an advantage over the legacy station. Again, minimizing CWmin considerably prioritizes the enhanced station, as can be seen in the figure.

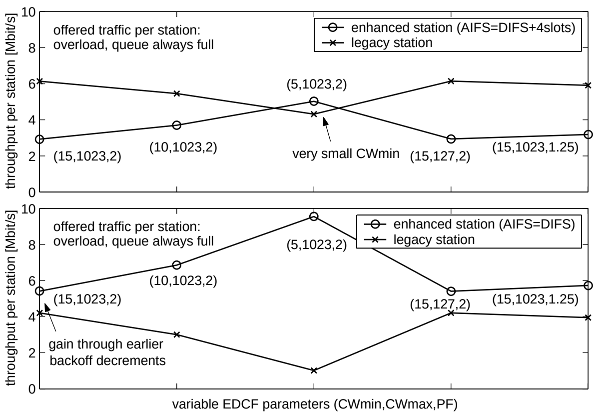

Fig. 13: Throughput in contention with a legacy station.

4.5 QoS guarantee with HCF

We now evaluate the polling scheme of the HCF, which is affected by the maximum duration of EDCF-TXOPs. Fig. 14 shows the resulting MSDU Delivery delay distributions for an isolated QBSS as indicated in Fig. 7. The AP carries an additional isochronous downstream which is delivered through HCF. The data frames of this stream are immediately transmitted after PIFS when the medium is detected as idle. Note that the HCF achieves its strict delay requirements by setting a maximum TXOP duration for all other streams. Fig. 15 shows resulting delays for an increased offer at the low and medium priority streams. Only the HCF stream stays within its maximum delay limit. In contrast, if we allow longer MSDUs to be transmitted through the lower priority streams, i.e., if we increase the EDCF-TXOP limit, the maximum delivery delay of the HCF stream increases as well, see Fig. 16. Here we simulate the same offer as in Fig. 14, but with longer data frames. The MSDU sizes of TC0 and TC5 now exceed the fragmentation threshold. However, the increased delay of TC7 only happens if the HC specifically allows such long MSDUs to be transmitted within a TXOP.

There is another situation of significantly increased MSDU Delivery delays, which is not under the control of the HC and is therefore undesirable. When more than one QBSS operate in an overlapping scenario at the same time, even polled data frames of highest priority suffer from an unpredictable delay and throughput degradation due to uncoordinated resource sharing between HCs. See Fig. 17 for an example where we simulated two overlapping QBSSs. It can be seen that now the delays of the high priority stream exceed the TXOP limit defined by the HC, which attempts to limit the MSDU Delivery delays of TC7 to *300 us*. Note that the given result is an example for a variety of delays and throughputs that can be observed in overlapping QBSSs. One observable example occurs, if the two HCs always poll at the same time. Then all poll frames collide, and the throughput of TC7 drops down to zero. In this case no resulting delay curve for TC7 can be given at all.

For the overlapping QBSS problem, solution concepts are under discussion at the standardization group. One solution would be to apply dynamic frequency selection, to let a QBSSs dynamically select a free channel. Other approaches are based on policies.

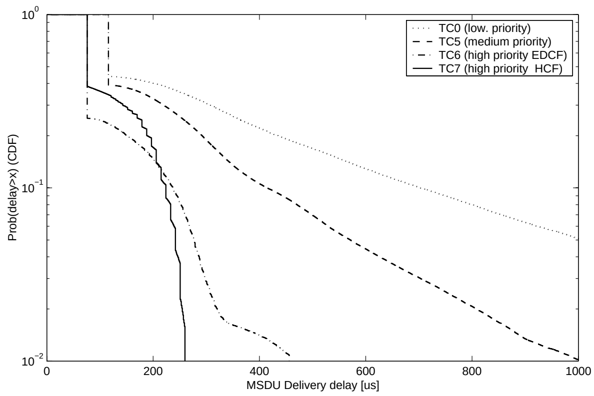

Fig. 14: HCF MSDU Delivery delays in an isolated QBSS with five stations.

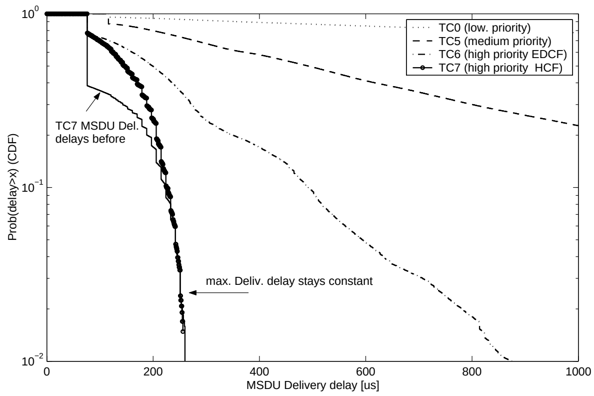

Fig. 15: HCF MSDU Delivery delays in an isolated QBSSs with five stations and increased offered EDCF traffic.

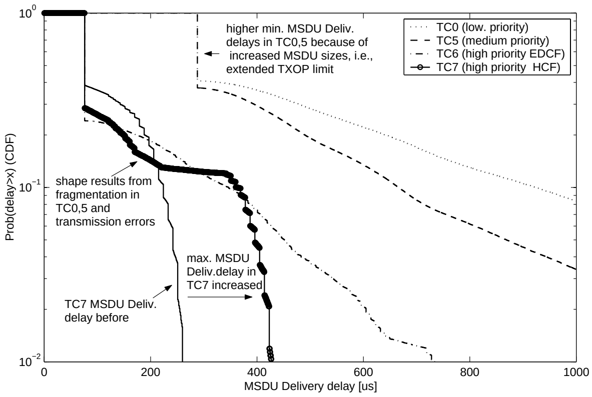

Fig. 16: HCF MSDU Delivery delays in an isolated QBSS with five stations, with increased MSDU sizes (*400 bytes* instead of *200 bytes*) of the EDCF traffic.

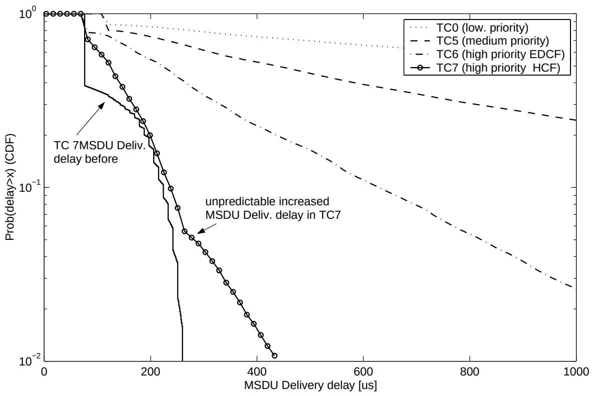

Fig. 17: HCF MSDU Delivery delays in two overlapping QBSSs with five stations per QBSSs. The delays of TC7 are an example and may be different in other overlap situations. They obviously depend on the transmission times of the data frames within the different isochronous streams.

5. SUMMARY AND CONCLUSIONS

A comprehensive overview of the new QoS supporting features of 802.11e compared to the legacy 802.11 is presented. New mechanisms for QoS support, i.e., the EDCF and HCF, are evaluated. Their performance is discussed via the simulation results. The upcoming 802.11e standard will be an efficient mean for QoS support in WLANs for a wide variety of applications, although open problems such as the overlapping QBSS still remain to be solved. Even with legacy stations operating in DCF, stations operating in EDCF are able to achieve priority over the legacy stations. The HCF provides the means for delivering time-bounded traffic, but requires all stations within the range of the HC to follow its coordination.

The focus of our future work includes the etiquettes and policies for distributed QoS guarantees in overlapping QBSSs, dynamic frequency selection, and multi-hop networks, which are crucial for multimedia home networking environments.

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