QoS Traffic in Wireless LAN Overlapping Cells

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***Abstract*: The IEEE 802.11 standard is playing an increasingly important role in next generation mobile radio networks. In order to fulfill the requirements of such networks, the Wireless LAN technology has to provide mechanisms for transporting Quality-of-Service (QoS) enabled traffic in large Wireless LAN deployments. In this paper, we show that the existing Medium Access Control (MAC) protocols perform well within single cell scenarios, but their performance drops drastically in environments with overlapping cells. Therefore, we evaluate the robustness of the Enhanced Distributed Channel Access (EDCA) MAC protocol in different scenarios with overlapping cells.**

1. Introduction

Wireless Local Area Networks (WLAN) complying to the family of IEEE 802.11 [1] standards gained an enormous importance in recent years. The advantages of WLAN in the context of 4th Generation Mobile Networks (4G) are clearly the high data rates of currently up to 54 Mbps, the license free spectrum, and the cheap hardware. The major drawback is the lack of Quality-of-Service (QoS), which is one of the advantages of other wireless systems. To be able to support QoS in WLAN networks, the IEEE formed the IEEE 802.11e task group in 2001. The work of the task group is completed, as they have forwarded the 802.11e-D13.0 [2] to RevCom for final approval. The extension basically defines two different approaches: an extended version of the existing polling scheme as well as a distributedly controlled prioritization scheme based on the Carrier-Sense Multiple Access with Collision Avoidance (CSMA/CA) medium access control mechanism. Both mechanisms can support QoS in single cell scenarios, i.e. cases where only a single Access Point (AP) is used.

In the context of 4G systems, this might not be sufficient. The IEEE 802.11b [3] and IEEE 802.11g [4] standards allow the largest coverage areas and are thus the most interesting for large-scale deployments. However, they only support up to three non-overlapping channels. Therefore, it is easy to see that it is not possible to cover large areas such as office buildings without the problem of an overlap in AP coverage and frequency band. As we have already shown in [5], these overlaps cause great problems even for best-effort traffic. It can thus be expected that the consequences on QoS mechanisms that are based on similar mechanisms will be even worse. Therefore, we study the different QoS mechanisms in overlapping cells. Most studies about the IEEE 802.11e draft standard ignore these scenarios and focus on the single-cell cases [6, 7]. The only papers which address overlapping cells are from Stefan Mangold [8, 9]. The first paper focuses on fair radio resource sharing by applying the Transmission Opportunity Limit (TXOPLimit) bursting. In the second paper, simulation results are presented with these TXOPLimits bursting together with a slotting scheme.

The paper is organized as follows. In Section 2 the QoS MAC protocol is explained. Section 3 summarizes the simulation approach used in order to evaluate the QoS capabilities. The results are shown in Section 4. Finally, Section 5 concludes the paper.

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2. Wireless LAN QoS MAC protocol overview

The basic Medium Access Control protocol CSMA/CA *(Distributed Coordination Function (DCF))* defined for Wireless LAN allows a distributed access with equal medium share only. The simple polling mechanism of the *Point Coordination Function (PCF)* mode on the other hand is not sufficient for large-scale deployments. Therefore, more advanced mechanisms have to be considered. The IEEE 802.11e standard defines such an extension. It specifies two enhancements of the basic mechanisms which are together referred to as *Hybrid Coordination Function (HCF)*. One enhancement aims at the polling mechanism while the second extends the DCF mechanism. For our simulation runs, we only use the extended DCF mechanism, which is called Enhanced Distributed Channel Access (EDCA) [2].

2.1. Enhanced Distributed Channel Access (EDCA)

In contrast to the DCF, EDCA is based on different priorities. The contention window and backoff times are adjusted to change the probability of gaining medium access to favor higher priority classes. It supports eight different priorities from 0 to 7 as defined by the IEEE 802.1D [10] standard, shown in Table 1. These priorities are mapped to four Access Categories (ACs) as shown in Figure 1. ACs are sorted from AC0 to AC3 with AC3 having the highest priority for medium access. The service differentiation according to these ACs is achieved by varying the amount of time a station senses the channel to be idle before starting the contention window (carrier sensing interval), the length of the contention window to be used, and the duration a station may transmit after it acquires the right to transmit (TXOPLimit).

For each Access Category (AC) an enhanced variant of the DCF called Channel Access Function (CAF) contends for the medium using a set of EDCA parameters

User Priority	802.1D Designation	AC	Designation (Informative)
1	Background (BK)	0	Best Effort
2	-	0	Best Effort
0	Best Effort (BE)	0	Best Effort
3	Excellent Effort (EE)	1	Video Probe
4	Controlled Load (CL)	2	Video
5	Video (VI)	2	Video
6	Voice (VO)	3	Voice
7	Network Control (NC)	3	Voice

Table 1: User Priority to Access Category Mapping

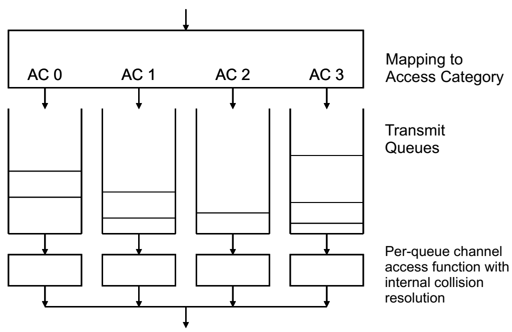

Figure 1: HCF Access Categories

from the EDCA Parameter Set element. Each CAF represents a virtual DCF STA with own parameters. The EDCA parameter set used by each CAF is defined by the Arbitration Interframe Space, AIFS Number, CWmin, CWmax, and TXOPLimit.

In DCF mode, a STA uses a carrier sensing interval of Distributed Interframe Space (DIFS) to decide if the medium is idle. In EDCA mode, different time intervals are used. These AIFSs are usually longer time periods as the DIFS. Therefore, a certain prioritization can be reached. If two stations want to transmit at the same time, the station with the shorter IFS will get access. Therefore, lower priorities use larger IFSs in EDCA mode.

In EDCA mode, the backoff procedure of the DCF is changed. The basic mechanism defines, that a number of backoff slots is taken from the interval of $[0, CW]$. The number is chosen uniformly distributed. Initially the CW value is set to the value CWmin. Whenever a packet loss occurs, the CW value is increased by $CW' = (CW + 1) \cdot 2 - 1$ until the maximum value CWmax is reached.

For DCF mode, the default values are $CWmin = 31, CWmax = 1023$. EDCA uses these values to define different priorities. A typical parameter set for EDCA is shown in Table 2. Here, the highest priority class is assigned a CWmin value of 7 and a CWmax value of 15 while the lowest priority class is assigned the values 31 and 1023. This will lead to different mean contention window sizes. Clearly, a STA with a lower mean contention window will get access to the medium much more often. Thus, a prioritization can be reached. A more detailed description of the EDCA mechanism can be found in [2], [11], or [12].

AC	CWmin	CWmax	AIFS [s]
0	31	1023	5.00E-05
1	31	1023	3.00E-05
2	15	31	3.00E-05
3	7	15	3.00E-05

Table 2: Access categories and Their Values

3. Simulation Environment

In this section we introduce the simulation model that was used to retrieve the results. This includes the simulation scenarios as well as the modeled user behavior in terms of application usage. All scenarios were simulated using the OPNET Modeler [13] with a complete implementation of the MAC layer, based on the IEEE 802.11e standard. We have chosen a simulator because the QoS extension is not yet implemented in any Access Point and an analytical model is rather complex in terms of overlapping cells scenarios.

3.1. Simulation Scenarios

In order to cover larger areas, such as whole office buildings, a number of Access Points have to be deployed to get a complete coverage. As already mentioned earlier, the WLAN standard IEEE 802.11b only allows up to three non-overlapping channels and no power control has yet been implemented for this standard. Considering the large-scale environment and the restricted number of channels, it becomes obvious that there are always some areas where AP coverage overlaps in terms of location and channel.

3.1.1. Overlapping Cells

In an overlapping cell scenario two Access Points are used to cover an area, but the Access Points are far enough apart to be out of the reception range of each other. This is the most important way to deploy large Wireless LAN hot spots, since such a setup optimizes the coverage area.

The three possible scenarios for overlapping cells are shown in Fig. 2. In the following Client C1 is always associated with Access Point A1 while Client C2 is solely connected to Access Point A2. The first overlapping cells scenario shows the coverage areas of the two Access Points A1 and A2 as black solid circles around the nodes. The two Wireless LAN Clients C1 and C2 are placed in the coverage area of both APs. In this scenario both clients will experience the same problems caused by the overlap. The reception range of the two clients is indicated by the gray circles.

Scenario B changes the position of Client C1. It is not in the reception range of AP A2, but will still receive the packets transmitted by the other Client C2. The Client C2 is still in the coverage area of both Access Points. Finally, in Scenario C Client C1 is placed farther away from AP A2 and Client C2. It is now only in the re-

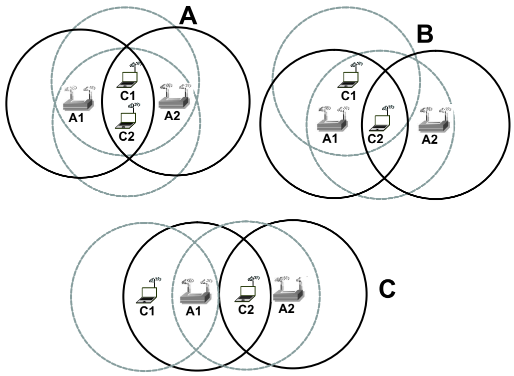

Figure 2: Overlapping Cells Simulation Scenarios

ception range of its associated AP A1. Client C2 is still located in the area covered by both APs.

3.2. Traffic Model

The users in our simulations do not move. They are located at the positions as specified in the simulation scenarios described above. They use the QoS Wireless LAN MAC protocols of the IEEE 802.11e standard and the IEEE 802.11b data rate of 11 Mbps on the physical layer. Voice applications are supplied with the highest priority. The next highest level is applied to video transmissions, while the background FTP traffic always gets the lowest priority, see Table 1. The way the different applications were implemented is explained in the following.

3.2.1. FTP Traffic Model

To evaluate the prioritization mechanisms of the IEEE 802.11e standard, non-prioritized background traffic has to be considered as well. The most common best-effort application is the World Wide Web. However, the simulation of WWW users demands very long simulation runs in order to account for the high variability of traffic. Therefore, FTP traffic is considered as a worst-case scenario of Web traffic.

3.2.2. Voice Traffic Model

In order to minimize the bandwidth required by a voice client, different voice compression algorithms are evaluated. The most important voice codecs are G.711 (64 Kbps), G.729 (8 Kbps), and G.723.1 (5.3 or 6.3 Kbps). Earlier studies regarding the suitability of voice codecs in Wireless LAN scenarios indicated that the inter-arrival time between consecutive voice packets has the highest impact on the number of voice clients within a single Access Point due to the large overhead in Wireless LAN packets. The data rate only has a minor impact. Therefore, the G.723.1 codec with an inter-arrival time of 30 ms is considered here. The data rate 6.3 Kbps is used, in order to increase the quality of the encoded voice stream. The Perceptual Evaluation of Speech Quality (PESQ)[14] is used to evaluate the quality of the voice stream. The PESQ value is transferred from an objective quality scale to a subjective Mean Opinion Score (MOS) value as defined in [15]. The MOS provides a value be-

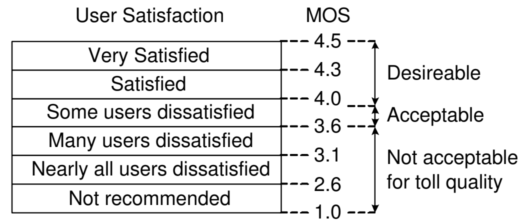

Figure 3: Mean Opinion Score (MOS) using PESQ

tween 1 and 4.5 as shown in Fig. 3. These MOS values can be mapped to a subjective interpretable value reaching from *desirable* to *non-acceptable* based on different speech characteristics.

3.2.3. Video Traffic Model

As in the case of voice traffic, there are several different video codecs that can be used to compress the video. The most important standard for video streaming and video conferencing is H.263. The video streams used for the simulations are 2-minute video sequences. These sequences are encoded using the Common Intermediate Format (CIF) with 352x288 pixels. From these randomly chosen sequences, the worst-case video was chosen. The term "worst-case" refers to the statistics of average frame size and variance. The quality of the received video is evaluated using the Peak Signal to Noise Ratio (PSNR). The details of how to obtain the PSNR can be found in [16] and [17]. As for the PESQ value for voice traffic, the PSNR value of a transmitted video stream can be mapped to MOS values as defined in Table 3.

Quality	PSNR [dB]	MOS
Excellent	≥ 37	5
Good	[31; 37)	4
Fair	[25; 31)	3
Poor	[20; 25)	2
Bad	< 20	1

Table 3: PSNR to MOS Mapping

4. Results

First, we consider the overlapping cells Scenario B. It is asymmetric, since only Client C2 is in the overlap of both APs, while Client C1 is not disturbed by the data transmission from AP A2. Client C2 uses a QoS demanding application, while Client C1 downloads files from the Access Point A1. In the following, Client C1 uses 1 MByte file downloads. If the file is completed, a new FTP connection will be established and another 1 MByte file is requested. This means that the Client C1 tries to utilize the complete WLAN capacity of Access Point A1.

In the case of voice traffic and standard DCF or EDCA operation, the MAC protocol can not provide an acceptable VoIP service for Client C2. In the DCF mode, the mean packet loss, caused by packet collisions, for the voice Client C2 reaches 59.97%, which maps to a MOS score of 1.0 meaning *not recommended*. In EDCA mode, the average packet loss for Client C2 even reaches 63.54% and again a MOS score of 1.0.

This is clearly not acceptable. DCF cannot provide any QoS, such that the results for DCF mode are not surprising. However, EDCA with standard parameters already applies a higher priority to the voice client than to the best-effort user. The problem is that with the standard parameters of CWmin=7, CWmax=15, the collision probability is very high, since a retransmission attempt is performed rather quickly. Therefore, we can conclude that such small contention window parameters are not suitable for the overlapping cells Scenario B.

In order to overcome these problems, we adapt the contention window parameters as shown in Table 4. A set of priority classes is defined according to different CWmin and CWmax values. In the following, we will apply these priority settings to the two involved clients to find a better choice.

Class	0	1	2	3	4	5	6
CWmin	7	15	31	63	127	255	511
CWmax	15	127	255	511	1023	2047	4095

Table 4: Wireless LAN Priority Classes

When applying these new contention window parameters to the stations, the results are as shown in Table 5. For completeness, the results corresponding to the default DCF and EDCA modes are shown as well. It can be seen that an acceptable solution for this problem can only be found when applying the priority classes (5,X) or (6,Y) with $X \in \{1,2\}$ and $Y \in \{1,2,3,4,5\}$. In case of priority class (4,1) and (4,2), the MOS lies below 2.6 and leads to a user satisfaction which is *not recommended*. For priority classes (6,1), (6,2), (6,3), and (6,4) the voice quality is still *acceptable* with just a few dissatisfied users. For priority classes (5,1), (5,2), and (6,5) the voice quality drops just below *acceptable*.

MAC Protocol	Priority Class C1	Priority Class C2	Packet Loss C2 [%]	MOS Score
DCF	default	default	59.97	1.0
EDCA	default	default	63.54	1.0
EDCA	4	1	7.64	< 2.6
EDCA	4	2	8.29	< 2.6
EDCA	5	1	0.53	3.428
EDCA	5	2	0.77	3.371
EDCA	6	1	0.00	3.704
EDCA	6	2	0.04	> 3.6
EDCA	6	3	0.03	> 3.6
EDCA	6	4	0.03	> 3.6
EDCA	6	5	0.39	3.535

Table 5: Scenario B: MOS values (1 MByte FTP files)

The results show that C1 must at least have priority class 5. These results are summarized in Figures 4 and 5. The 99%-quantile of the end-to-end delay of the voice application is shown in Fig. 4. It proves that in scenarios with varying FTP load (depending on the FTP file size), the results that were described above still hold. One drawback of lowering the priority setting of the best-effort FTP user can be seen in Fig. 5. It shows the average throughput in KBps that the FTP user will experience. Clearly, the lower the priority (larger value means lower priority), the lower the average throughput will get.

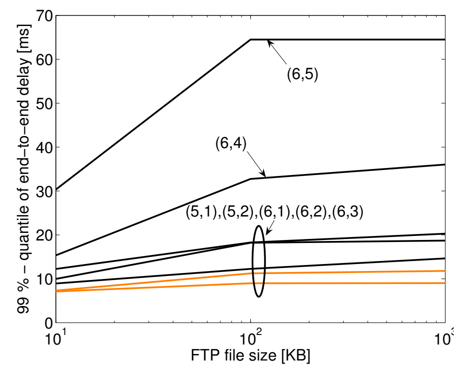

Figure 4: Scenario B: Voice Delay

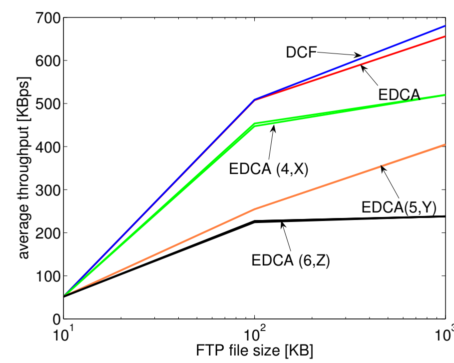

Figure 5: Scenario B: FTP Throughput (Voice)

However, as it seems more important to provide QoS service than maximum throughput in the Wireless LAN scenarios considered here, choosing a priority setting of (5,X) is a good compromise. A good FTP performance can still be reached without interfering with the voice application.

In case of video traffic, the results are as shown in Table 6. It can be seen that priority classes (4,1) and (5,Y) with $Y \in \{1,2,3\}$ only provide *fair* video quality (MOS=3). If the priority set (6,Z) with $Z \in \{1,2,3,4\}$ is used, the MOS value changes to 5 indicating *excellent* video quality. The PSNR is always above 37 in all simulation runs.

Again Fig. 6 shows the 99%-quantile of the end-to-end delay in ms for the video applications. Fig. 7 depicts the average throughput the FTP user experiences when applying different priorities.

Thus, for overlapping cells Scenario B it can be concluded that when applying different priority settings to the voice, video, and best-effort user, it is possible to

Priority Class C1	Priority Class C2	Packet Loss C2 [%]	PSNR	MOS Score
default	default	86,19	12.66	Bad
4	1	6.84	25.45	Fair
5	1	5.67	25.69	Fair
5	2	6.01	24.60	Fair
5	3	6.34	26.55	Fair
6	1	0.07	40.67	Excellent
6	2	0.19	40.97	Excellent
6	3	0.43	46.84	Excellent
6	4	0.53	45.27	Excellent

Table 6: Scenario B: PSNR values (1 MByte FTP files)

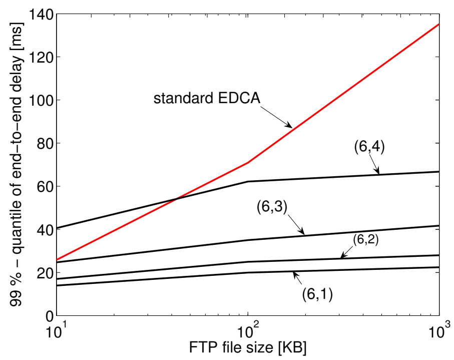

Figure 6: Scenario B: Video Delay

provide QoS and still allow the FTP user to get an acceptable throughput rate. Different priority settings are possible and can be used by a wireless service provider to adapt the settings to his specific needs.

Overlapping cells Scenario A is the only symmetric scenario. Therefore, both clients are located in the overlap and both will experience problems in the case of default EDCA parameters. However, since both clients experience the same problems, the solution is even easier than in the former case with overlapping cells Scenario B. Here, the priority settings of (3,1) and (4,1) are already sufficient. This means, that the priority of the FTP user can be higher here, compared to the former case. This allows the FTP client to receive an even higher share of the bandwidth than before.

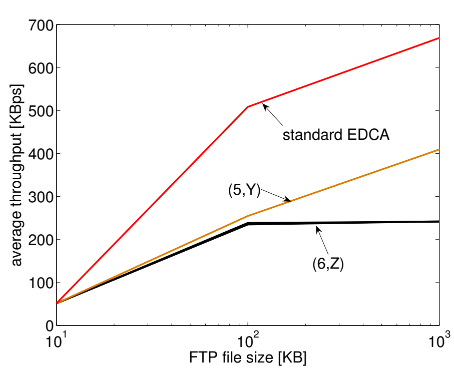

Figure 7: Scenario B: FTP Throughput (Video)

Due to the symmetric nature of the overlapping cells Scenario A, the FTP client will experience a much higher packet collision probability than in the overlapping cells Scenario B. Therefore, packets are finally dropped after the maximum number of retransmission is reached on WLAN MAC layer. The TCP protocol underlying the FTP application performs a packet retransmission. However, a retransmission on the TCP layer also leads to a reduction of the data transmission rate, which leads to a lower load on the wireless medium and to a lower packet collision probability. Ultimately, the performance degradation of the FTP client allows a better quality for the voice client.

Overlapping cells Scenario C on the other hand, behaves almost exactly like overlapping cells Scenario B. If we configure the scenario with a priority setting (6,1), meaning Client C2 has a CWmin value of 15 and Client C1 has a CWmin value of 511, the Mean Opinion Scores for voice and video traffic are the same as in Scenario B.

The simulation Scenarios D and E, shown in Fig. 8, are used to verify our results in cases with more than two clients. Therefore, we first place two more FTP clients in the scenario which also perform an FTP download from A1 as shown in Scenario D in Fig. 8. With this scenario setting the load of Client C1 decreases due to the fact that it has to compete with the other FTP clients in the network. The quality of the multimedia applications at Client C2 does not decrease because of the large backoff intervals of the FTP clients.

Finally, we place one more voice Client C3 in the network as shown in Scenario E in Fig. 8. In contrast to voice Client C1, this client is now connected to Access Point A1 and not in the transmission range of Access Point A2. This new Client C3 has the same priority setting as the Client C2 in the overlap. If we simulate this scenario, we see that the quality of Client C3 is acceptable which was expected because of a larger priority than the FTP client. The quality of the voice Client C2 decreases but is still acceptable.

The goal of the QoS enabled MAC protocols is to provide QoS for voice and video applications at the same time. In order to evaluate our priority settings for such a case, we simulated the worst case scenario (overlapping cells Scenario B) with Client C2 using voice and video at the same time. Client C1 performs FTP downloads. The priority setting chosen was (6,2,1), meaning that the voice application uses priority class 1, the video application was configured to use priority class 2, while the best-effort FTP traffic was handled with priority class 6. The results are shown in Table 7.

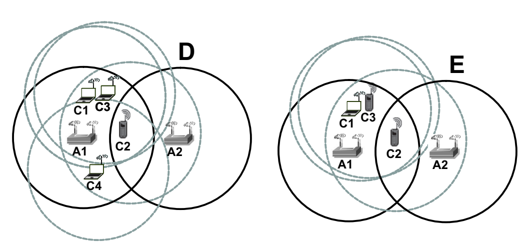

Figure 8: Overlapping Cells Simulation Scenarios

Traffic Type	Priority Class	Packet Loss [%]	End-to-End Delay 99%-quantile [ms]	End-to-End Delay Maximum	MOS Score
Voice	1	0.03	10.77	22.12	>3.6
Video	2	0.27	34.94	59.53	5

Table 7: Combined solution (1 MB files), Voice and Video

It can be seen that EDCA with priority class (6,2,1) can provide adequate QoS even if both multimedia applications are used in a single station. The same simulation with EDCA default parameters results in packet loss for both voice and video applications above 80% and this certainly provides bad voice and video quality. The best-effort FTP user suffers a performance degradation in terms of average throughput of about 50% to 60%. However, the immense potential in providing QoS in large-scale Wireless LANs surely compensates for this.

5. Conclusion and Outlook

In our studies we focus on the newly standardized MAC protocol known as *Enhanced Distributed Channel Access*. It defines ways to assign different priorities to the involved stations. Large-scale deployments of Wireless LAN have the additional problem of overlapping cells in terms of coverage and channel. Therefore, we performed simulation studies that evaluate the QoS capabilities of EDCA in case of overlapping cells.

These simulation studies clearly show that the proposed prioritization parameters are not sufficient in scenarios with overlapping cells. They can prioritize certain stations, but they lead to high levels of packet loss, and thus to large quality degradation in case of voice and video applications. Our studies show that different sets of prioritization parameters can be applied that will provide the required level of prioritization while still allowing a high medium utilization. If we choose a priority setting of (6,2,1) which means that the voice application always gets the highest priority, the video application the second highest priority, and an FTP application the lowest priority, it is definitely possible to support QoS traffic in every Wireless LAN environment, even if we have overlapping cells. The only disadvantage of applying these changes of the contention windows is that the FTP throughput decreases in comparison with the settings proposed by the IEEE 802.11e draft because of the larger backoff times.

Future work will focus on co-located cells, where the Access Points are in the reception range of each other. An appropriate planning process should try to avoid these situations, but as more wireless operators start their service while private users set up their own private hot spots, these scenarios are definitely possible in practice. Therefore, we will look if our priority setting of (6,2,1) still holds in these scenarios. Furthermore, we try to develop an analytical model for overlapping-cells scenarios to verify the results presented in this paper.

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