The Main Benefits of Applying IEEE802.11e in Access Networks with Possible Roaming Users

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This paper discusses the possible benefits of deploying IEEE 802.11e in relation to scenarios where residential WLANs are used for public access. Three main features are discussed:

- The Direct Link Protocol, which makes it possible to communicate directly between STAs for internal communications (without going through the AP);
- EDCA, which makes it possible to differentiate between Access Categories;
- TXOP limits for fair utilization of the channel.

The actual benefits are discussed for a scenario where both residential and roaming user-traffic competes for the WLAN capacity. The example shows a large improvement in WLAN performance by deploying IEEE 802.11e in such an environment.

Introduction

This paper addresses some of the potential benefits IEEE 802.11e may have (compared to legacy IEEE 802.11) when deploying WLAN as an open access network that may also be applied for roaming users, like e.g. the concept studied in the IST OBAN project [1][2]. The main intention is to try to quantify the benefits of applying the features of the IEEE 802.11e when it comes to the possibility of differentiation among user classes and different traffic types.

In a series of papers [3]–[9], we have addressed different aspects of the performance of the wireless LAN based on IEEE 802.11e analysis protocol under non-saturation condition. This is different from most other work published where saturation conditions are employed. By analytical modelling we have analysed the following important key performance parameters:

- Starvation effects seen in the lower priority classes in IEEE 802.11e;
- Throughput per priority class as a function of the offered input traffic;
- Delays including MAC delay, waiting times in queues and total delay for higher layer protocols where both mean delay and delay distributions are given.

The actual analytical models are suitable tools for evaluating the benefit of IEEE 802.11e when using residential WLANs for public access; however, the actual benefits depend on the scenario. A set of scenarios are selected for discussion. It should be noted that when the channel resources are abundant, the benefits of IEEE 802.11e are less dominant. It is mostly in cases where there is scarcity of channel resources that IEEE 802.11e is of the highest interest, and where its features really come into play.

A brief overview of IEEE 802.11e

During recent years the IEEE 802.11 WLAN standard has been widely deployed as the most preferred wireless access technology in office environments, in public hotspots and in the homes. The IEEE 802.11 medium access control (MAC) comprises the mandatory Distributed Coordination Function (DCF) as a contention-based access scheme, and the optional Point Coordination Function (PCF) as a centrally controlled polling scheme. However, PCF is hardly implemented in any products, and DCF represents the commonly used MAC mechanism of 802.11. DCF adopts carrier sense multiple access (“listen-before-talk”) with collision avoidance (CSMA/CA) and uses binary exponential backoff. A station not only goes into backoff upon collision. It also carries out a “post-backoff” after having transmitted a packet, to allow other stations to access the channel before it transmits the next packet.

Due to the inherent capacity limitations of wireless technologies, the 802.11 WLAN easily becomes a bottleneck for communication. In these cases, the QoS features of the 802.11e standard will be beneficial to prioritize for example voice and video traffic over more elastic data traffic.

The IEEE 802.11e standard works as an extension to the 802.11 standard, and the Hybrid Coordination Function (HCF) is used for medium access control. HCF comprises the contention-based Enhanced Distributed Channel Access (EDCA) as an extension for DCF, and the centrally controlled Hybrid Coordinated Channel Access (HCCA) as a replacement for PCF.

EDCA has received most attention recently. The reason is that the Wi-Fi Alliance has already “standardized” a subset of the 802.11e standard, called Wi-Fi MultiMedia (WMM). EDCA is the major part of...
WMM, while HCCA is not included. Furthermore, WMM has been available off-the-shelf, and various Access Points and interface cards support EDCA through WMM.

Since this document focuses on what is possible to implement now or within the next year, EDCA is of primary interest here. However, although HCCA will not be discussed any further in this document, one should be aware that it may provide additional features that might prove valuable in the OBAN context as soon as these features are available in off-the-shelf products.

EDCA enhances DCF by allowing four different access categories (ACs) at each station and a transmission queue associated with each AC. Each AC at a station has a conceptual module responsible for channel access for each AC and in this paper the module is referred to as an Enhanced Distributed Channel Access Function (EDCAF). Hence each of the four transmission queues (and the associated ACs) on a station is represented by one backoff instance. The channel access between different backoff instances on a station is not completely independent due to the virtual collision handling between the queues on the station. If two or more backoff instances on the same station try to access the channel in the same timeslot, the station attempts to transmit the frame of the highest priority AC, while the lower priority frames will go through backoff.

The traffic class differentiation of EDCA is based on assigning different access parameters to different ACs. First and foremost, a high-priority AC, $i$, is assigned a minimum contention window, $W_{0,i}$, that is lower than (or at worst equal to) that of a lower-priority AC. At a highly loaded (or “saturated”) medium, the post-backoff of the high-priority AC will normally be smaller than the post-backoff of a low-priority AC. This results in an average higher share of the channel capacity, because the high-priority AC will on average have to refrain from the channel for a shorter period of time than the low priority AC. Furthermore, each AC is assigned a maximum contention window, $W_{m,i}$, so that a higher priority AC has a lower or equal maximum contention window compared to an AC of a lower priority.

Another important differentiating parameter is the Arbitration Inter-Frame Space (AIFS) value, measured as a Short Interframe Space (SIFS) plus an AIFSN number of timeslots. A high-priority AC is assigned an AIFSN that is lower than (or at worst equal to) the AIFSN of a lower-priority AC. The most important effect of the AIFSN setting is that the high-priority AC normally will be able to start earlier than a low priority AC to decrement the backoff counter after having been interrupted by a transmission on the channel. At a highly loaded channel where the decrementing of the backoff counter will be interrupted by packet transmissions a large number of times, the backoff countdown of the high-priority AC will occur at a higher average speed than that of the lower-priority AC. As the wireless medium gets more and more congested, the average number of empty timeslots between the frames transmitted by the higher-priority ACs might be lower than the AIFSN value of the low-priority AC. At this point, the AC will not be able to decrement its backoff counter, and all packets will finally be dropped instead of being transmitted. This is referred to as “starvation”.

Finally, another differentiation parameter that may be adjusted in 802.11e is the Transmission Opportunity (TXOP)-limit of each AC, $i$. This means that an AC may hold the channel only for a time interval determined by the TXOP-limit.

Selecting a scenario with roaming users

Assumptions

There are three major assumptions behind the selected scenario:

1. The access is divided between devices of the home user (HU) and devices of visiting (Roaming) users (VU).

2. The home user wants a soft guarantee that its sessions are not undermined by a sudden peak usage by the visiting users.

3. There is an ongoing trend that home users deploy the “Residential Gateway”, i.e. the Access Point, as a hub for a wireless infrastructure in the home. (Figure 1)

An example of a vendor applying the 802.11 technology for wireless infrastructure in the home is Philips “Streamium” products. A large number of products are already available (see Figure 2). Philips focuses mainly on using the wireless infrastructure for streaming of music, video (e.g. DVD), entertainment and gaming.

Bit rates and 802.11 physical layer

There are three possible 802.11 PHYs that are natural to explore:
Figure 1  The Residential Gateway (i.e. Access Point) forms a hub for a wireless communication in the home

<table>
<thead>
<tr>
<th>Access every thing</th>
<th>Connect every thing</th>
</tr>
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<tbody>
<tr>
<td>Wi-Fi wireless flat TV 23PF9976i/23iF9946</td>
<td>Wireless base station 802.11b/g</td>
</tr>
<tr>
<td>Wi-Fi wireless home entertainment system MX6000</td>
<td>Wireless USB adapter 802.11b/g</td>
</tr>
<tr>
<td>Wi-Fi wireless micro-Hi-fi system MC i250</td>
<td>Wireless notebook adapter 802.11b/g</td>
</tr>
<tr>
<td>Wi-Fi wireless multimedia link SL400i</td>
<td>Wireless base station 802.11b/g</td>
</tr>
<tr>
<td>Wi-Fi wireless multimedia link SL300i</td>
<td>Wireless USB adapter 802.11b/g</td>
</tr>
<tr>
<td>Wi-Fi wireless music link SL300i</td>
<td>Wireless notebook adapter 802.11b/g</td>
</tr>
<tr>
<td>Wireless PC-link micro HiFi system MCW770</td>
<td>Remote control RC9800i</td>
</tr>
<tr>
<td>Touchscreen</td>
<td></td>
</tr>
</tbody>
</table>

Figure 2  A large number of Streamium products are already available
1 802.11b:
   • Max nominal rate: 11 Mb/s
   • Are found in new and old products, i.e. most useful today

2 802.11g: Are found in all new products
   • Max nominal rate: 54 Mb/s
   • Are found in new and old products, i.e. most useful today.

Note that the nominal bandwidth does not give the total throughput. Typically, one will only get maximum 6 Mb/s (or most probably less) when using 802.11, despite the nominal bandwidth of 11 Mb/s.

In this document we use 802.11b as an example. The reason is that the 802.11b and its performances are well known. However, all the analyses in this document are applicable to 802.11g and 802.11n, simply by scaling up the generated traffic load as compared to the nominal bandwidth offered by the technology.

Unless explicitly stated otherwise, we assume that all stations have perfect radio conditions. The reason is that this document does not want to discuss details of radio effects or get into radio range discussions.

It should be noted that it is easy to find usage scenarios where the home user experiences the wireless medium as a bottleneck for communication, no matter which of the PHYs that are studied. It has been shown that 802.11g is a bottleneck for the widespread use of products like e.g. Streamium from Philips, and one would hope that 802.11n will provide sufficient bandwidth for a normal usage of such products.

**A Basic Scenario**

Let us assume that the father in the home is sitting in the living room watching a movie, where a DVD is streamed from a PC (PC1) in the house to the set-top box that is connected to the TV. The daughter is sitting in her room watching a music video that is located on her brother’s PC (PC2). For simplicity we assume that the streaming is undertaken at a constant bit-rate. Figure 3 illustrates the example.

At the same time, there are a number of Visiting Users. To this end, we consider three different scenarios:

1 4 visiting users: This is probably the most common scenario.

2 10 visiting users: This can be a probable scenario, e.g. for a house located close to a bus station.

3 25 visiting user: This will be a typical “hotspot” scenario.

The visiting users are sending and reading e-mail, using an e-mail web-account (e.g. yahoo-mail or google-mail). They use best effort http communication at a variable traffic rate.

**Potential Benefits of 802.11e**

**The Direct Link Protocol**

Consider a scenario where two stations are associated with the same AP, for example the “TV Setup Box” and the “PC1” in Figure 3. With legacy 802.11, communication between the stations is always relayed via the AP, as illustrated in the figure.

However, 802.11e provides a feature called the Direct Link Protocol (DLP). With DLP, the two stations can use the AP to negotiate a direct link between them (Figure 4). When DLP has been used to set up the link, all subsequent data traffic between the two stations is sent directly between the two stations without having to be relayed via the AP (Figure 5).
As seen from Figure 5, approximately only half of the channel capacity is required for the direct communication with DLP as compared to not using DLP. This feature is particularly useful for the home user devices, because there will probably be communication between these devices. It is not very useful for the visiting users, because they will probably rarely communicate with other visiting users located at the same AP. (An exception is if two Visiting Users meet face-to-face and want to exchange some files, but this is not anticipated to be very common.) The benefits of DLP for the visiting users will therefore be neglected here.

**Without 802.11e**

Let us assume that 802.11 gives approximately 6 Mb/s user traffic. Without DLP, the home user spends approximately 4 Mb/s of the channel bandwidth, leaving only 2 Mb/s for the visiting users and only 200 kb/s per visiting users in the scenario with 10 visiting users per AP.

**With 802.11e**

If DLP is being used, the home user device needs only 2 Mb/s and leaves 4 Mb/s to be used by the visiting users. This gives 400 kb/s per visiting user in this example.

**EDCA differentiation between Access Categories**

Another feature of 802.11e is that EDCA provides differentiation between different traffic classes. This means that it is possible to set access parameters of the AC in such a way that one AC is protected against an excessive traffic rate of the other AC. The benefit of this protection is that admission control will not often be required to implement such protection, and the lower priority AC can maximize the channel use without having to care about not stealing capacity from the higher priority AC.

In order to exemplify this, we will use the analytical model for 802.11e EDCA, which we have developed in the OBAN project. Another option would be to use simulations. However, we have demonstrated through a number of presentations that the analytical model is fairly accurate, and minor inaccuracies will not have impact on the main conclusions.

In order to study the basic scenario, we make some simplifying assumptions. We assume that there are four home user devices, each sending traffic at a constant bit rate of 1 Mb/s. At the same time, we assume that there are four visiting users, sending at a variable bit rate.

Figure 6 shows this scenario, where the total throughput of the home user and the visiting users is plotted as a function of the traffic rate generated by the visiting users. It is observed that the throughput of the home user is being gradually reduced as the throughput of the visiting users is increasing. Hence, without
802.11e there is no protection between the home and visiting users.

Figure 6 also shows the queuing delay of the home user’s traffic and the queuing delay of the visiting users’ traffic. It is observed that the queuing delay of the home user’s traffic goes to infinity before the queuing delay of the visiting users’ traffic. That means that it is the home user’s communication that will primarily suffer when the traffic rate of the visiting user increases. When the visiting users send at a traffic rate of 1600 kb/s, for example, the queuing delay of the visiting users’ traffic will be around 18 ms, while the queuing delay of the home user’s traffic will be infinite. This means that the visiting users will be able to communicate without problems, while the traffic generated by the home user will be stacked on transmission queues or dropped due to buffer overflow.

To avoid a too high level of jitter, it is probably wise to restrict the visiting user’s traffic to approximately 1300 kb/s. In this case, the home user is guaranteed the required bandwidth at a controllable level of jitter.

Figure 7, on the other hand, shows the same scenario but with the EDCA being used to differentiate between the home user’s and the visiting users’ traffic. Here the home user uses the default parameter settings of 802.11e for AC_VO (priority voice / real time) traffic, while the visiting users use the default parameter settings for AC_BE (best effort) traffic. It is observed that the throughput of the home user does not decrease considerably (except for some minor inaccuracies of the model) when the traffic of the visiting users is increasing. The traffic of the visiting user increases up to a certain point where it will not get any more traffic. Hence, the traffic differentiation mechanism of 802.11e can provide protection between the home user’s and visiting users’ traffic.

Figure 7 also shows the queuing delay of the home user’s traffic and the queuing delay of the visiting user’s traffic. Here it is observed that the queuing delay of the visiting user’s traffic goes to infinity before the queuing delay of the home user traffic. That means that it is the visiting users’ communication that will primarily suffer when the traffic rate of the visiting users increases. When the visiting users send at a traffic rate of 900 kb/s, for example, the queuing delay of the visiting users’ traffic will be infinite, while the home user will be able to communicate without problems with a queuing delay of less than 4 ms.

The advantage in this example is that the visiting users can communicate as much as they want without having to consider the communication of the other nodes. The visiting users’ traffic will not even result in any considerable jitter for the home user, since the maximum queuing delay that the visiting users can cause to the traffic of the home user is less than 4 ms. Since the visiting users will be using TCP for communication, TCP will sense the queuing delay and reduce the traffic when the bandwidth roof is hit. Hence, the visiting user can communicate freely and let TCP handle the bandwidth constraints.

**Without 802.11e**

If 802.11e is not being used, some kind of admission control is needed. The visiting users must share a bandwidth of 1300 kb/s, *leaving each of the four visiting users with only 325 kb/s*.

**With 802.11e**

If 802.11e is being used, *each visiting user can normally spend all available 900 kb/s*. With the packet bursting of typical http traffic, the visiting users will seldom experience a situation where many stations access the channel at the same time. Thus, most often the visiting user will have all the 900 kb/s available for its own use. On some occasions, two of the visit-
ing users will retrieve and send an e-mail at exactly the same time, and will each receive a bandwidth of only 450 kb/s. And so forth.

Needless to say, if there are more than four visiting users the benefits of 802.11e will be bigger, because of the inefficiency of static bandwidth sharing per station of the OBAN admission control procedure when 802.11e is not used.

**Using TXOP limits for fair utilization of the channel**

A very OBAN-relevant feature of 802.11 is that the wireless channel is accessed on a per-packet basis, and each station holds the channel until the packet is sent, independent of the length of the packet.

An important problem with this feature in this context is that the visiting users are often outside the house at the border of the coverage area of the access point and with degraded radio conditions. Often the interface may adapt and send traffic at a more robust modulation, e.g. sending the data traffic at 1 Mb/s instead of at 11 Mb/s. The result is that a 1024 byte packet sent at 1 Mb/s will take almost seven times as much time on the channel as a packet sent at 11 Mb/s.

The following shows that channel time consumed by a 1024-byte packet sent at different maximum nominal rates:

- 11.0 Mb/s: 1.321 ms
- 5.5 Mb/s: 2.065 ms
- 2.0 Mb/s: 4.672 ms
- 1.0 Mb/s: 8.768 ms

A big question is – is this fair? Is this a reasonable way of utilizing the channel resources? How to protect the home user from the inefficient bandwidth utilization of the visiting users? A key point is that the visiting users will not only receive low bandwidth. In receiving this bandwidth it is anticipated that they will at the same time consume an unreasonable amount of the bandwidth of the home user. Let us explore this in detail and show that this intuitive fact is correct.

The curves for the given visitor rate of 11 Mb/s in Figure 8 are the same as the ones shown in Figure 6; i.e. in the scenario where 802.11e is not used. In this scenario it was assumed that both the home user’s devices and the visiting users’ devices had perfect radio conditions and could all communicate at a maximum nominal radio rate of 11 Mb/s.

We now assume, however, that the visiting users have bad radio conditions and can only communicate at 1 Mb/s. This situation is illustrated by the brown and blue curves in Figure 8.

Figure 8 shows that the visiting user obtains a theoretical maximum throughput of only 46 kb/s, i.e. 12.5 kb/s per visiting user, since the nominal bit rate is reduced to only 1 Mb/s. (This is also illustrated in Figure 9.) In doing so, the visiting users consume a big share of the channel bandwidth so that the theoretical maximum throughput of the home user is reduced to less than 2 Mb/s (Figure 8).

Figure 9 shows how the visiting users’ throughput changes at a smaller scale. It is seen that the throughput evolves more or less along the input = output line. That means that most of the traffic gets through and is not stacked on queues. In Figure 8, on the contrary, we observe that the home user, on the contrary, reduces its throughput almost immediately. Since only a small fraction of the traffic are dropped due to exceeded retry counters, most of the traffic that are not sent here, are stacked on queues. It is seen that the queueing delay occurs at a very low throughput value of the visiting users.

![Figure 8 Effect of the lack of the TXOP limit when the Visiting users communicate at 1 Mb/s (without 802.11e)](image-url)
Hence, another and considerably more alarming consequence of this effect is that the queueing delay of the home user will reach the upper limit very soon as the visiting users start to send a few kilobits per second. In other words, the visiting users will easily destroy the possibility for the home user to communicate, as soon as the visiting users start communication.

Let us also compare the effects of the lack of TXOP limit when 802.11e is used. The curves for the case of visiting users given 11 Mb/s in Figure 10 are the same as the ones shown in Figure 7; i.e. in the scenario where 802.11e is used. In this scenario it was assumed that both the home user’s devices and the visiting users’ devices had perfect radio conditions and could all communicate at a maximum nominal radio rate of 11 Mb/s. Two upper curves in Figure 8 (showing the throughput for home users with visited user-rate of either 1 or 11 Mb/s), on the contrary, illustrate a situation where the visiting users have bad radio conditions and can only communicate at 1 Mb/s. Indeed, Figure 10 shows that the problem is the same also with 802.11e differentiation.

802.11 states that an EDCAF cannot hold the channel more than the channel time given by the TXOP limit. Assume that the TXOP limit is set to 1.5 ms, which is a reasonable setting in 802.11e. The result is that the home user will be able to send all its packets as before, because each packet (with a duration of 1.3 ms) is below the TXOP limit.

The visiting users, on the contrary, will need a number of TXOPs in order to get the 1024 byte packet sent. In fact, at 1 Mb/s, the visiting users are able to send a packet every 1.3 ms, which is not enough to send the whole packet. Indeed, Figure 10 shows that the problem is the same also with 802.11e differentiation.

It should be noted that our analytical model needs to be adopted to study the queueing delay with different nominal bit rates when TXOP limits are not used. Our experience is that development of the model requires considerable resources.

The TXOP-limit feature of 802.11e provides a solution to the problem presented until this point in this subsection, as shown in Figure 8 – Figure 10. Let us now explain the feature and then explore the potential benefits of this feature.

802.11 states that an EDCAF cannot hold the channel more than the channel time given by the TXOP limit. Assume that the TXOP limit is set to 1.5 ms, which is a reasonable setting in 802.11e. The result is that the home user will be able to send all its packets as before, because each packet (with a duration of 1.3 ms) is below the TXOP limit.

The visiting users, on the contrary, will need a number of TXOPs in order to get the 1024 byte packet sent. In fact, at 1 Mb/s, the visiting users are able to
send approximately 115 bytes of data within the time limit of 1.5 ms. This means that the visiting user need to fragment each packet into nine fragments that are sent independently in separate TXOPs. Since 802.11 channel access works on a per-packet basis, it is now mostly the visiting users that will suffer, while the home user will not experience any major changes. However, the home user will notice that the traffic intensity — in terms of number of packets sent by the visiting users — increases, since the number of packet fragments sent on the channel increases.

Figure 11 shows the effect of using TXOP limits of 802.11e, when 802.11e differentiation is used. It is observed that the use of the TXOP limit fully protects the traffic of the home user. The fact that the visiting users are located far away from the AP with poor radio conditions puts the burden on these visiting users. Thus, it is no more a situation of the visiting users being able to obtain a few kb/s more bandwidth at a tremendous cost of the home user’s bandwidth.

Figure 11 shows that the visiting users hits the capacity limitation before they try to transmit more than 100 kb/s. In order to study what really happens at traffic rates below 100 kb/s, we need to see Figure 11 on a smaller scale. This is shown in Figure 12.

Figure 12 shows that the home user is more or less unaffected by the fact that the visiting users are communicating at 1 Mb/s. It also shows that the queueing delay of the visiting user goes to infinity at a traffic rate of approximately 98 kb/s. Figure 12 reveals a remarkable result compared to Figure 8; it shows that the TXOP feature provides the visiting users with at least twice the available bandwidth without destroying for the home user. In Figure 8, on the contrary, we saw that the visiting users got less than 46 kb/s at a tremendous expense of the home user’s ability to communicate.

Similar to our previous summaries, we may conclude this subsection with the following:
Without 802.11e without TXOP_limits
If 802.11e is not being used, some kind of admission control is needed. The visiting users must share a bandwidth of 46 kb/s, leaving each of the four visiting users with only 12.5 kb/s. The home user gets very little through, typically in the order of 100 kb/s or so. [In order to estimate the limit for the home user, we need to enhance the analytical model, so that the queuing delay can be found.]

With 802.11e and TXOP-limits
If 802.11e is being used, each visiting user can normally spend all the available 98 kb/s. With the packet bursting of typical http traffic, the visiting users will seldom experience a situation where many stations access the channel at the same time. Thus, most often the visiting user will have all the 98 kb/s available to their own use. On some occasions, two of the visiting users will retrieve and send an e-mail at exactly the same time, and will each receive a bandwidth of only 46 kb/s. And so forth. On the other hand, the home user can continue to spend approximately 4 Mb/s, because the TXOP-limits protect it from the fact that the visiting users are communicating at 1 Mb/s nominal bit rate.

Downlink Fairness
802.11 works on a per-station (or per-EDCAF) basis. Thus, the downlink traffic will easily be subject to unfair treatment compared to uplink traffic.

Work is going on within the framework of EDCA and we hope to explore the benefits of 802.11e for such fairness, as it will indirectly influence on the capacity benefits that 802.11e will provide compared to a solution based only on legacy 802.11.

Other Potential Benefits

802.11e Admission Control
802.11e provides a feature for dynamic admission control at the link layer. This gives much closer operation with the actual link layer and thus offers an opportunity for more efficient exploitation of the radio resources.

HCCA
HCCA provides an additional channel access mechanism. We believe that HCCA will be particularly important in the downlink scenario, because 802.11 works on a per-station (or per EDCAF) basis. Thus, the downlink traffic will easily be subject to unfair treatment compared to uplink traffic. This can be solved within the framework of EDCA, however; HCCA provides an additional mechanism that might prove to be very useful.

Conclusions
It is shown that the following features of 802.11e might be of particular importance in an access network allowing for roaming users:

- Direct Link Protocol
- EDCA differentiation between Access Categories
- TXOP-limits

A scenario was presented as a starting point for the analysis, and the quantitative benefits of the various 802.11e features have been presented based on the scenario.

For simplicity, we have used 802.11b as the physical layer technology for our scenario, because the technology and its capabilities are well known in terms of for example bandwidth capacity. It is however straightforward to scale up the analysis to a scenario for a situation using the 802.11g PHY or the 802.11n PHY. In fact, we have already used very conservative throughput values so that the analysis should be more applicable to higher capacity PHYs. For example, for the streaming traffic of the home user, we have assumed a traffic rate of only 1 Mb/s. However, DVD, for example, typically runs at a traffic rate of 4–9 Mb/s. Thus, a simple upscale of our analysis would require a PHY that lies in the borderline between 802.11g and 802.11n. It is not the scope of this document to get into a detailed discussion about what are realistic traffic rates of the scenarios.

References


8 Engelstad, P E, Østerbø, O N. The Delay Distribution of IEEE 802.11e EDCA. *Proceedings of the 25th IEEE International Performance Computing and Communications Conference (IPCCC'06)*, Phoenix, Arizona, 10–12 April 2006. (See also: www.unik.no/~paalee/PhD.htm)

9 Engelstad, P E, Østerbø, O N. Analysis of the Total Delay of IEEE 802.11e EDCA. *Proceedings of IEEE International Conference on Communication (ICC'2006)*, Istanbul, 11–15 June 2006. (See also: www.unik.no/~paalee/research.htm.)

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