Dynamic QoS Configuration of IEEE 802.11e WLANs: An Empirical Assessment

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Abstract. In this paper we use an implementation of an access selection architecture, whose main goal is to foster the *Always Best Connected* paradigm over heterogeneous wireless environments, cornerstone of the Mobility Concepts for IMT-Advanced (Mobilia) project, to enhance quality of service, by means of an integration with the IEEE 802.11e architecture. We provide an upper bound of the performance which might be achieved with this extension and afterwards, using a fully experimental approach, we show the enhancements which can be obtained by dynamically configuring the operational parameters of the subjacent MAC mechanisms.

1 Introduction and Objectives

This paper tackles the challenges which are brought about by two of the aspects with a greater relevance in the communication realm at the time of writing; the first one is the growing presence of wireless communication technologies, which have already become a commodity everyone makes use of; on the other hand, we also consider the stringent quality of service (QoS) requirements that novel services (many of them comprising multimedia, real-time, traffic) pose.

The two aforementioned aspects bring about some difficulties, due to the intrinsic characteristics of wireless technologies, which make them unsuitable to transport real-time traffic. This limitation is even worse for one of the most widespread technologies, namely IEEE 802.11; from its original release in 1997, the standard has lacked from an appropriate set of mechanisms to guarantee minimum quality of service levels. In this case, the fact that all the users share the same wireless medium adds another remarkable obstacle. However, the IEEE 802.11e amendment, published in 2005, offered some new capabilities regarding the assurance of certain QoS levels. It is worth mentioning that, in parallel with these new elements, the standard has still aimed at boosting the raw communication performance, and this implies new MAC mechanisms.

Despite the remarkable relevance of this set of new functionalities, there are not many works which have actually tackled their evaluation over real platforms, and to our best knowledge, there are not any proposals on how to make use of their possibilities dynamically, by taking into account the particular requirements of the current services. In this paper we precisely aim at covering this two

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aspects. In this sense we benefit from the architecture which has been designed in the framework of the *Mobility Concepts for IMT-Advanced (Mobilia)* project in order to empirically assess the enhancements and improvements offered by the IEEE 802.11e mechanisms. Furthermore, we follow a completely empirical approach, since all the measurements and tests are performed over a real platform, which incorporates a fully-fledged implementation of the aforementioned architecture.

In order to cover those aspects, the paper is structured as follows: Section 2 presents the Mobilia architecture and summarizes the main elements of the IEEE 802.11e extension, discussing how they are integrated; Section 3 discusses some available works which share some of the characteristics of this one. Section 4 presents an empirical analysis of the maximum performance which could be expected when applying some of the mechanisms which have been introduced to the basic IEEE 802.11 MAC protocol, while Section 5 discusses the improvements which can be achieved when using multiple traffic flows (with different QoS requirements) and the possibilities of the IEEE 802.11e architecture are smartly used. Finally, Section 6 concludes the paper, advocating some items that are left for future works.

2 Mobilia Architecture and IEEE 802.11e Integration

This section introduces the Mobilia architecture and revises the main characteristics of the IEEE 802.11e extension. It also discusses how to tackle the integration of both entities.

2.1 The Mobilia Architecture

The Mobilia architecture is thought to foster optimum access selection in wireless heterogeneous environments, reaching the *Always Best Connected* paradigm. It shares some of the characteristics of other similar proposals (see e.g. [8] and the references therein).

As can be seen on Figure 1 it embraces three main entities: the *Abstraction Layer (AL)* hides the particularities of the subjacent wireless technologies to the upper entities, so that they can be compared on a homogeneous way. Each of the involved technologies would require an interface towards the *AL*, which is given by the so-called *Link Layer, (LL)*. The combination of both the *LL* and the *AL* facilitates the operation of the *Handover and Decision Manager (HoDM)*, which is in charge of selecting the most appropriate access considering a set of different parameters, like service requirements, end-user policies and preferences, etc.

One of the key elements of the Mobilia architecture is that all signalling is based on the IEEE 802.21 specification [15,3], which it is believed to be a focal point in forthcoming communication environments, since it promotes a media-independent signalling to facilitate handover mechanisms. Another remarkable aspect of the work carried out is that we have a working platform with such architecture included [6].

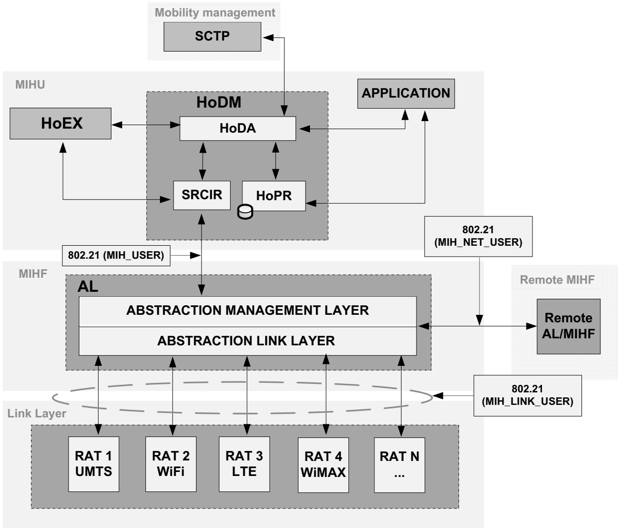


Fig. 1. Mobilia architecture overview

2.2 Review of the IEEE 802.11e Extension

The ammendent IEEE 802.11e [1] was approved in November 2005. It was proposed as the framework to boost the *Quality of Service (QoS)* over WLAN. This extension introduces a new function called HCF (Hybrid Coordination Function), which allows the stations to establish a multiple-queued system, in order to guarantee a prioritized access to the radio channel for those nodes which require some priority level. For that purpose, it defines a new channel access method, *EDCA* (Enhanced Distributed Channel Access), a distributed and contention-based mechanism, successor of the legacy DCF (Distributed Control Function). Each station divides the transmission into four queues (Access Categories or AC's) before sending any data, according to its traffic type, such as Voice, Video, Best Effort and Background[1]. Each AC selects different CW_{min} and *AIFS* (Arbitrary InterFrame Space)[2] values (the greater the priority, the shorter the value and thus the waiting time to access the channel).

Furthermore, *EDCA* establishes some new channel utilization procedures, based on the principles of the *Multiple Frame Transmission during a Transmission Opportunity* and *Block Acknowledgement*. The first one consists on a period, established by the *TXOP* (Transmission Opportunity) parameter, during which a station could take the channel access, being able to send frames continuously, without contending for a new access (i.e. the station sends a new

[1] Any message is mapped to one of these four queues.

[2] This one is equivalent to the DIFS used in the legacy IEEE 802.11, but in this case each AC has its own AIFS.

frame after a *SIFS* instead of the *DIFS + Backoff* pair), and until this *TXOP* period expires. However, the election of this parameter must be chosen wisely, because a long interval could induce a starvation situation over the channel, by having a station monopolizing the transmission. On the other hand, the *Block ACK* mechanism allows a block of frames to be transmitted without sending an ACK after each frame; the two entities involved in the communication would have negotiated an unique acknowledgment at the end of the block.

In addition, the recently approved IEEE 802.11n extension [2] has included some proprietary techniques, whose main goal consists on increasing the raw throughput as much as possible, by reducing the overhead introduced by the MAC layer. The first one is known as *A-MSDU (Aggregation MAC Service Data Unit)* by the standard, and consists on the aggregation of several *SDU's* into one single *MAC Protocol Data Unit (MPDU)*; i.e. grouping several upper-layer frames into one MAC frame. This technique was previously implemented by some manufacturers, such as Atheros, who named it as *Fast Frames*. Similarly, Atheros incorporated the possibility to transmit multiple frames within a TXOP interval, as specified by IEEE 802.11e, naming it as *Bursting*[3].

2.3 IEEE 802.11e Integration into the Mobilia Architecture

One of the main advantages of having a fully operational implementation of the Mobilia architecture is that it can be used so as to assess the benefits of different functionalities. In this sense, although it was originally designed to foster optimum access selection, it can also be used to tweak the operational parameters of the interfaces considering the particular characteristics of the wireless medium and/or the requirements of the services.

As it has been said before, the operation of the IEEE 802.11e mechanisms is configurable, and thus the idea would be to modulate the current parameters depending on the information managed by the *HoDM* entity, which concerns both the service requirements and the particular condition of the available networks.

In order to promote the integration of this on the Mobilia platform, there are two additional pieces to be used. The first one is the *netfilter/iptables* framework [14]. Its role would be to modify the *Type of Service, ToS* field of outgoing IP datagrams according to the commands sent by the *HoDM*; the *Service Requirements Collector Information Repository (SRCIR)* was used to house this new functionality, which can be used dynamically, adjusting the operational parameters depending on the changing conditions of the network. The second element, which has been also incorporated into the *SRCIR*, handles the communication with the IEEE 802.11e interfaces, so as to change their operation, as instructed by the corresponding decision engines. In the running Mobilia platform, which is based on IEEE 802.11 *Atheros* chipsets (with the `madwifi` driver [12]), this can be done anytime by using the appropriate `ioctl` commands. Section 5 will describe the enhancements that this approach can bring about.

[3] From now on, we will use the *Fast Frames* and *Bursting* nomenclature so as to refer these techniques.

3 Related Work

The vast majority of available works around the IEEE 802.11e recommendation have focussed on TCP fairness issues and most of these performance analysis have been based on simulations and analytical models [16]. One of the first empirical studies was carried out by Leith et al [11]. Using a test-bed with one PC acting as an AP and 12 PCs acting as client stations, all of them equipped with Proxim/Atheros cards working at 11 Mbps, they modified the MadwiFi wireless driver to adjust the AIFS, TXOP and CWmin parameters in order to ensure fairness between competing TCP uploads and downloads. More recently they have extended their prior investigation to multi-hop wireless networks [4].

Another empirical work which focuses on voice transmission over an 802.11e network is based on delay measurements for voice packets when contending with data flows. More precisely, Dangerfield et al [7] carried out their study with the 802.11b standard and stated that only 5 contending data stations are needed in order to cause a voice call loss rate above 10%, which represents an acceptable level of voice quality. This is one of the first studies that experimentally analyzes one way delay measurements to provide some degree of priorisation of voice in an 802.11e test-bed.

In a recent work [5], the authors study the impact of layer 2 frame aggregation. Through experimental measurements they show that throughput values may vary up to 25% for certain packet sizes, while the variance of inter-frame delays at the receiver station almost double when MAC aggregation is not used, especially for voice traffic, which increases its jitter values up to 8 times.

If we consider transmission of a more demanding type of traffic, like video streaming, over an 802.11e network, a recent work by Haywood et al [10] studies the behavior of this type of traffic using three different assignment schemes: using DCF thus managing all the traffic equally, assigning video traffic to each of the access classes, and assigning the packets according to their priority class. Moreover, TCP data traffic from three clients using the best effort class is added to the video traffic. With such scenario, this study shows that video quality can be improved through appropriately assigning packets to wireless access classes compared to the legacy best effort scheme, and, what is more relevant, the single class assignment can achieve better performance than the multi-class assignment.

Following this trend, a comparison between EDCA and DCF schemes is shown in [13]. The authors investigate the behavior of both access methods on a test-bed by transmitting TCP and UDP streams representing traffic types such as FTP and VoIP. Although the achieved throughput and the delay are the main metrics of this study, other parameters, e.g. Signal to Noise Ratio, are obtained from the passive traffic captures. Such study determines that EDCA and DCF offer similar performances with single streams of traffic. The study concludes that the perceived loss rate might lead to similar performances for both EDCA and DCF, when single traffic flows are considered.

4 Empirical Characterization of IEEE 802.11e Mechanisms

4.1 Scenario

In order to characterize the radio channel in a real scenario, a WLAN cell has been established consisting of two nodes separated by a negligible distance to avoid losing frames due to channel effects. One node acts as an access point while the other one is configured as a station. Furthermore, external interference can also be neglected. A Proxim Orinoco Gold a/b/g Combo card has been chosen for the wireless network interface, as it is based on an Atheros chipset which uses the free MADWiFi driver, allowing its modification in order to fulfill the required configuration. The implemented scheme is as follows: the AP transmits a continuous UDP flow towards the receiving station (the bit rate is fixed for all experiments, disabling any auto-rate adaptation mechanisms [4]), which monitors the communication by extracting different types of data and values that will subsequently be processed to yield statistical and graphical results.

The use of UDP protocol ensure neither error nor flow control, and thus it is the perfect choice to exclusively analyze the link layer. Last, but not least, the wireless retransmission scheme has been disabled and therefore any damaged frame will be discarded.

4.2 Results

Radio channel characterization is accomplished by carrying out, for every configuration, a batch of 10 transmissions of 25000 frames each. After collecting all data from the different measurements as explained before, trace files will be analyzed focusing on two parameters: latency[5] and throughput, which are very closely linked as well. More specifically, time domain characterization of the channel is based on calculating the histogram of the delay, which reflects the effect of the medium access mechanism (CSMA/CA) and also allows achieving other statistical results like throughput or jitter.

Below, results obtained for the two physical extensions considered in this paper are shown. Default units are microseconds for time and megabits per second for binary rates (this corresponds to the real performance offered to the upper layers, discarding time and headers overhead).

a) 802.11b
As can be observed (Table 1 and Figure 2), the Frame Error Rate (FER)[6]is nearly negligible. Another relevant result is the high value for the latency, due probably to the existence of any other station contending for gaining

[4] We always use the maximum bit rate, i.e. 54 Mbps for IEEE 802.11g and 11 Mbps for IEEE 802.11b.

[5] We define latency as the time interval between the reception of two consecutive error-free frames.

[6] The FER is the ratio of erroneous frames over the total received ones.

Table 1. Results over 10 measurements with 25000 UDP datagrams ea. (802.11b)

	Legacy	Fast Frames	Bursting	FF + Bursting
Frame Loss Rate (FLR)	0.0163	0.00028	0.000096	0.00091
Frame Error Rate (FER)	$4.4 \cdot 10^{-5}$	$8.8 \cdot 10^{-5}$	$4.0 \cdot 10^{-5}$	$8.0 \cdot 10^{-5}$
Average latency [μs]	1903.97	1489.94	1649.59	1634.73
Theoretical avg. latency [μs]	1735	2838	1560	1560
Latency jitter [μs^2]	$530 \cdot 10^5$	$23 \cdot 10^5$	$3.2 \cdot 10^5$	$4.0 \cdot 10^5$
Throughput [Mbps]	6.18	7.90	7.14	7.21
Theoretical thput[Mbps]	6.78	8.29	7.54	7.54

access to the same radio channel, which leads to a slightly lower throughput. We can also see that by applying the aforementioned techniques, remarkable throughput improvements are achieved, yielding values up to 1.5 Mbps greater than the legacy mode.

Table 1 shows the performance figures, obtained after 10 independent experiments, which are close (difference is less than 10%) to the theoretical values [9].

b) 802.11g
In this case (Table 2 and Figure 3), frame error rate is around 10%, to which a 2% more must be added as over 500 frames are lost for every test, due to the collisions caused by other stations contending for the channel, since the scenario is not fully isolated. Statistical characterization of delay is also negatively affected because frames that are deferred for transmission may wait for longer than regular times, increasing parameters like average delay and its variance. As a result, Table 2 yields that there is a significant difference between the theoretical performance and the one achieved over the real channel.

By analyzing the different delay histograms we can clearly see the effect of the additional MAC enhancements (Fast Frames and Bursting), which might yield a gain of up to 45 % (the two techniques jointly activated for the IEEE 802.11g case). On the other hand, Figure 3(d) shows an unexpected behavior, since roughly half of the frames are sent without taking advantage from the Fast Frames MAC aggregation technique. As a consequence it is not possible to derive the Frame Lost Rate in this case, since the total number of transmitted frames cannot be known (at least with the particular configuration we were using). Besides, note that when the Fast Frames mechanism is activated, the obtained latency is even lower than the theoretical one, due to the fact that the monitoring tool assumes a minimum gap of 1 μs between the two frames grouped into the same MPDU.

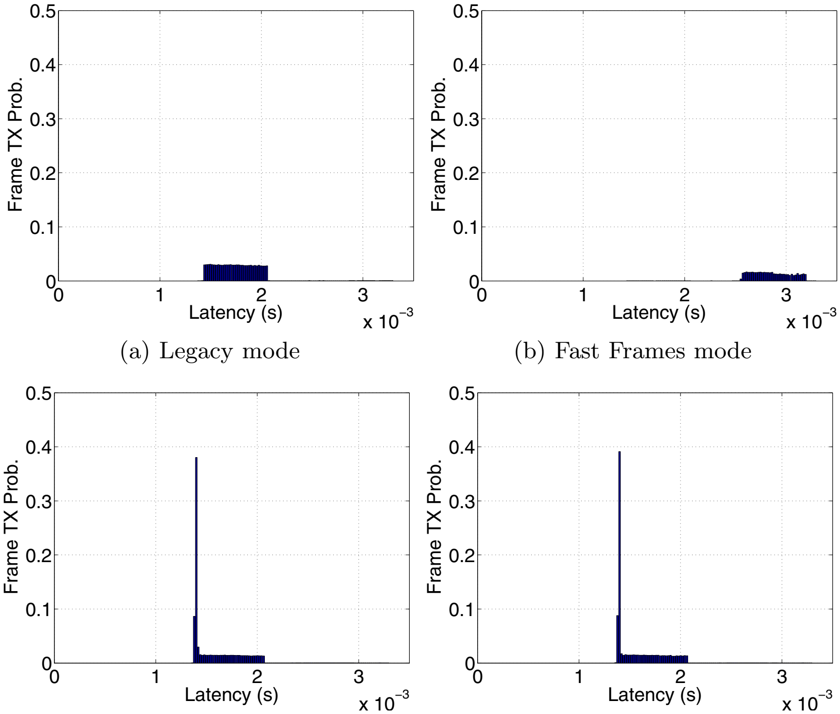
5 IEEE 802.11e QoS Proof-of-Concept

This section starts from the results obtained in the empirical characterization of the additional techniques over the IEEE 802.11 standard, studying the capacity

Table 2. Results over 10 measurements with 25000 UDP datagrams ea. (802.11g)

	Legacy	Fast Frames	Bursting	FF + Bursting
Frame loss rate (FLR)	0.02	0.018	0.0105	*
Frame error rate (FER)	0.1191	0.1534	0.0798	0.1154
Average latency [μs]	515.00	412.92	381.21	379.38
Theoretical avg. latency [μs]	390.16	607	316	543.72
Latency jitter [μs^2]	$200 \cdot 10^5$	$47 \cdot 10^5$	$100 \cdot 10^5$	$23 \cdot 10^5$
Throughput [Mbps]	23.39	28.39	31.48	32.9
Theoretical thput[Mbps]	30.18	38.74	37.26	43.31

* Unavailable, due to the receiver is not able to know the total number of frames sent.



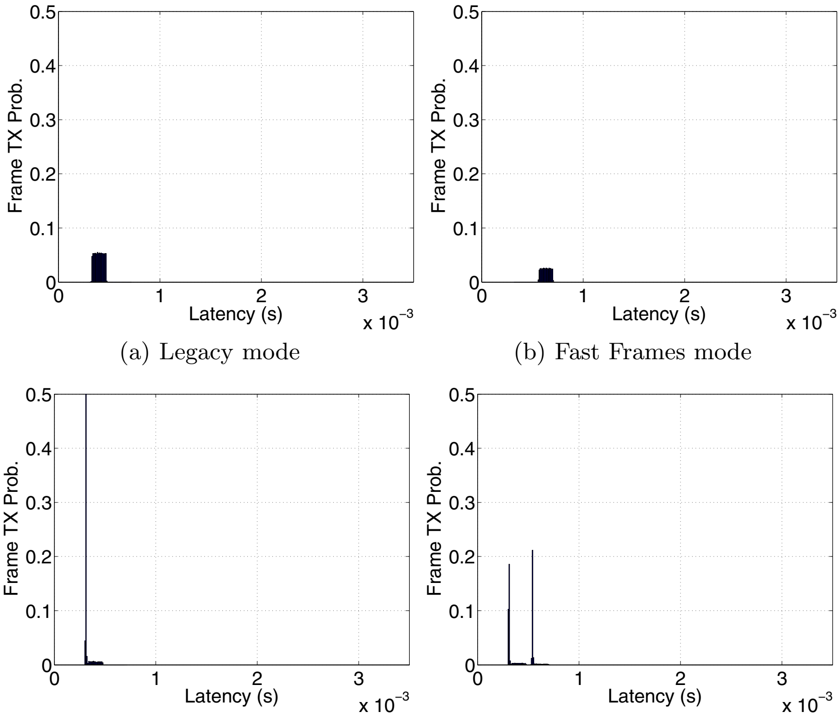
(a) Legacy mode (b) Fast Frames mode

(c) Bursting mode (d) FF + Bursting

Fig. 2. Delay histogram over analyzed techniques (802.11b)

bounds of several extensions over the basic standard, such as 802.11b and 802.11g and some Atheros proprietary techniques *(Fast Frames and Bursting)*, which were included in the 802.11n and 802.11e extensions, respectively.

At this point, it is worth revising the IEEE 802.11e extension, which provides QoS mechanisms to a wireless transmission. The medium access control mechanism divides the output traffic into 4 different access categories (we will refer to these as AC's in the future): Background, Best Effort, Video and Voice, sorted in ascending order, according to the priority requirements. In some cases, such



(a) Legacy mode
(b) Fast Frames mode
(c) Bursting mode
(d) FF + Bursting

Fig. 3. Delay histogram over analyzed techniques (802.11g)

as the two latter ones, there are some strict real-time conditions (delay timer and jitter), required to ensure a reliable service. Thus, IEEE 802.11e has to deal with these goals and be capable of assuring a series of conditions to the different services in order to make them reliable to the user.

Due to the results obtained in Section 4, we have decided to deploy the following scenario by using the IEEE 802.11b physical recommendation[7], since it was shown that the 802.11b will behave on a more reliable way, ensuring an almost error-free performance.

Table 3 shows the most relevant 802.11e parameters. The first four set the way that a frame contends for the channel access in order to be transmitted. For this reason, the last two columns show the theoretical bounds, in terms of throughput and latency [9] that correspond to each AC [8].

[7] Note that the goal is not to maximize the performance, but to thoroughly analyze the gain which might be obtained by using the various MAC extensions; therefore, IEEE 802.11b appears as the most appropriate choice, since it ensures a more reliable and stable behavior.

[8] These parameters are set by default. However, they might be configured in order to fit either the user preferences or the channel requirements.

Table 3. Default IEEE 802.11e parameters

	CW_{min}	CW_{max}	AIFSN	$TXOP_{limit}$	Th. thput [Mbps]	Th. latency [μs]
Background (BK)	31	31	7	0	6.41	1835.09
Best Effort (BE)	15	15	2	0	7.48	1575.09
Video (VI)	15	15	1	6016	8.24	1427.52
Voice (VO)	7	7	1	3216	8.23	1430.04

Derived from the scenario that has been depicted above, this section introduces a new platform that has been designed in order to demonstrate the possibilities the 802.11e brings about in order to add QoS mechanisms to a seamless transmission. As a result, we have designed a tool capable of generating as much QoS traffic as desired, configuring each AC individually (frame length, offered load[9] and finally either the transmission time or the number of frames to be sent).

Furthermore, we are able to modify the ToS field located in the IP header (by means of some Linux tools named *iptables*, which could set a TOS value from an UDP port number), so as to map the 802.11e AC.

First, we generate an overload situation, where a mobile node transmits using the whole channel capacity, sending traffic belonging to the 4 AC's simultaneously.

Figure 4(a) shows the bandwidth distribution for each access category assuming there is always traffic to be sent in the four categories. The difference between the two least important traffic classes can be easily seen, each of them uses a 5% of the total bandwidth, while the other ones monopolize the channel. Therefore, the figure yields that the IEEE 802.11e recommendation could actually provide a guaranteed QoS mechanism over a wireless link by tweaking the various configuration parameters, based on either the type of traffic or the node identifier.

Afterwards, we use off-the-shelf applications that generate a real traffic patterns, instead of the simulated one which was trasmitted by the IEEE 802.11e traffic simulator tool.

In this sense, we have measured the isolated requirements of a video streaming session generated by the VLC tool (mapped into VI queue) and a VoIP call using the Twinkle application (VO AC), so as to know their behavior when they act on their own.

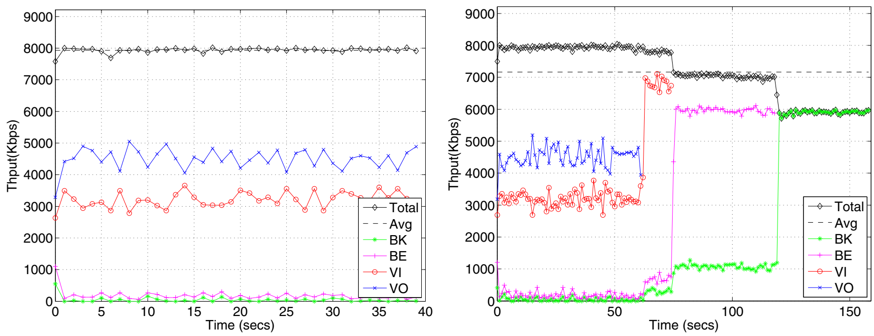
As a result, we are trying to prove that when these applications are merged with saturated traffic conditions from heterogeneous AC's, the standard achieves its goal by keeping the services on track.

Table 4 shows the different results (in terms of throughput and latency) between the aforementioned applications acting in an isolated way and when they have to contend for the channel access with other data flows, illustrating that the *EDCA* channel access ensures the transmission quality up for each of the

[9] The offered load (data bit rate) is fixed by setting the gap between two consecutive frames.

Table 4. Real applications performance characterization

	Isolated		Merged	
	VI	VO	VI	VO
Thput [kbps]	1257.8	15.6934	1289.2	10.0452
Delay [μs]	8157.7	20349	7979.4	20612
Jitter [μs^2]	$4.5 \cdot 10^7$	$2.5 \cdot 10^7$	$7.2 \cdot 10^7$	$3.9 \cdot 10^7$



(a) 40 seconds transmission (b) 25000 UDP datagrams

Fig. 4. Characterization over a saturated QoS scenario

two ACs, respecting always the priority-based queuing. We can see e.g. that the average delay does not change significantly and, albeit there is some increase, the variance is kept at affordable values.

Last, we have simulated another saturated scenario, similar to the first one, that is, it consists of sending simultaneously traffic at full capacity from the four AC's during a given time interval, excepting the fact that, in this case, we send the same number of UDP datagrams for each AC. Obviously, the transmission will finish according to the priority order: $VO > VI > BE > BK$, as can be seen on Figure 4(b). However, at the same time a queue stops transmitting, the global efficiency heavily drops, resulting in a 2 Mbps decrease when just the background AC is active. The reason behind this is that the parameters of the this particular queue lead to a longer average waiting time, which at the end correspond to inactivity periods.

Due to this unwanted loss of efficiency, the Mobilia architecture can be used to deal with the problem. In this sense, it will monitor the channel activity, by means of a real time channel listening, modifying the QoS parameters configuration according to the load situation over the radio channel, so as to avoid the inefficient default resource assignment. The final goal would be to provide the network with a smart system, able to ensure the maximum achievable performance, by appropriately (considering traffic paterns, link qualities, etc) tuning the corresponding QoS parameters.

6 Conclusions

This paper has conducted an empirical analysis of the enhancements which might be brought about by the IEEE 802.11e extensions, in terms of QoS guarantees. In order to achieve that, some modifications have been made to the Mobilia platform, which was originally designed to facilitate optimum access selection in heterogeneous wireless environments. It is able to use the particular network conditions and the characteristics of the traffic flows so as to modify the operational parameters of IEEE 802.11e, using the possibilities offered by *netfilter* framework and the `madwifi` driver.

Before that, a fully empirical analysis of the performance which could be expected by using some of the extensions proposed by different IEEE 802.11 amendments has been presented. This is of utter relevance, since it allows establishing an upper bound of the performance which can be expected with the various configurations.

The results which have been achieved show that there the performance could be heavily improved by making use of the possibilities provided by the IEEE 802.11e; furthermore, the use of the Mobilia architecture as an enabler for such enhancements has also been proved to be feasible.

The applicability of the available platform opens several lines of research, which we are currently exploring. First, we will add some more complexity on the measurement platform, by increasing the number of terminals accessing the channel; by monitoring the buffer lengths at the access elements, the *LL* might provide load estimations, which could be also used so as to modulate the operation of the MAC mechanisms. In addition, another possibility would be to increase the distance between transmitter and receiver, so as to decrease the link quality, taking this as another information element to tweak the operation of the subjacent MAC procedures.

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