A Protocol Enhancement for IEEE 802.11 Distributed Power Saving Mechanisms
No Data Acknowledgement

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Abstract—**Mobile devices including Wireless LAN functionality are becoming increasingly popular in society. The wide range of products available in the market target different customer needs but most of them should meet two main requirements: QoS support for differentiating real-time services from non real-time and power saving functionality to achieve an operating time according to users' expectations. The devices presenting the most challenging technical issues to meet these two requirements are dual-mode handsets (Cellular/WLAN) because of their mandatory support of a strict QoS demanding application, VoIP, and their small device size which severely limits the battery capacity. The focus of our work in this paper is the design and evaluation of an enhancement of the distributed Wireless LAN power saving mechanisms defined in the IEEE 802.11 and 802.11e standards, No Data Acknowledgment (NDACK). The objective of NDAck is to increase the battery lifetime of Wireless LAN mobile devices while providing the required QoS. The protocol improvement designed has been implemented in OPNET to evaluate the performance enhancements obtained. Our results show that i) NDAck significantly reduces the power consumption of stations running real-time applications, ii) the larger the power consumption due to the congestion in the wireless channel the larger the power consumption reduction with NDAck and iii) NDAck results in a considerable QoS improvement for real-time applications.**

Keywords—**Wireless LAN, 802.11, 802.11e, QoS, Power Save Mode and U-APSD.**

I. INTRODUCTION

The wide adoption of the IEEE 802.11 wireless LAN technology by home and business users, due to its capability of providing low cost high speed wireless Internet access, is driving a strong trend towards the inclusion of this technology in mobile devices like cellular phones, personal digital assistants (PDAs) or laptops. However, several challenges need to be addressed with respect to QoS and power saving limitations to achieve a seamless integration of the Wireless LAN technology in such devices.

Regarding QoS, an enhancement of the 802.11 MAC layer has been designed, the IEEE 802.11e standard [1], which defines mechanisms to provide QoS differentiation. IEEE 802.11e defines the Hybrid Coordination Function (HCF) to support QoS. Two channel access methods are defined: a contention-based method called the Enhanced Distributed Channel Access (EDCA) and a contention-free one referred to as HCF Controlled Channel Access (HCCA). Within a superframe two phases of operation are possible, contention period (CP) and contention-free period (CFP). HCCA can be used in both CP and CFP while EDCA can be used only during CP. A thorough overview of the 802.11e QoS enhancements can be found in [2].

With respect to the battery usage efficiency, the intrinsic nature of 802.11, which is based on a shared channel access (CSMA/CA), forces wireless stations to continuosly listen to the channel to determine its current status. As a result, a handheld device connected through an 802.11 wireless LAN, will drain its battery after a few hours as opposed to current mobile devices that can have a standby battery lifetime up to several days, e.g., cellular phones. Ideally, mobile devices including the Wireless LAN technology should achieve a battery consumption similar to current handheld devices in order to meet users' expectations.

The IEEE 802.11 standard includes a power save mode that reduces the time required for a station to listen to the channel. Once every Beacon interval, usually 100ms, the access point (AP) sends a Beacon indicating whether or not a certain station[1] has any data buffered at the AP. Wireless stations wake up to listen to Beacons at a fixed frequency and poll the AP to receive the buffered data by sending power save polls (PS-Polls). Whenever the AP sends data to a station, it indicates whether or not there are more data frames outstanding, using the More Data bit in the data frames, and a station goes to sleep only when it has retrieved all pending data. Although this mechanism significantly alleviates the power consumption problem, a dependency between the data frames MAC downlink delay (AP to station) and the listen interval is introduced. Consequently, some listen interval values can result in downlink delays unacceptable for certain QoS-sensitive applications, e.g., VoIP. Further details about the 802.11 power save mode operation can be found in [3].

In order to address the QoS issues that arise when 802.11 power save mode is used, the 802.11e standard includes an optional extension of the 802.11 power save mode defined as Automatic Power Save Delivery (APSD). Two different APSD modes have been defined depending on whether a distributed or a centralized mechanism is preferred. Unscheduled APSD (U-APSD) is a distributed mechanism where stations decide on their own when to awake to request the frames buffered at the AP while sleeping. Scheduled APSD (S-APSD) is the centralized mechanism where the AP determines a schedule for the stations to awake and receive the frames that the AP buffered.

New mobile devices incorporating 802.11e functionality are more likely to include first the *distributed* mechanisms of 802.11e, i.e., EDCA and U-APSD, than the *centralized* ones, i.e., HCCA and S-APSD. This can be seen for instance in the fact that the Wi-Fi^{TM} Alliance [4] has started first the certification of the Wi-Fi^{TM} Multimedia (WMM^{TM}) and the WMM Power Save^{TM} extensions, which include EDCA and EDCA

[1] In this paper the terms AP and station refer to what in the 802.11e standard is denoted as QAP and non-AP QSTA respectively.

plus U-APSD functionalities respectively, while certifications for HCCA and S-APSD are being deferred.

Our work in this paper focuses on a proposed enhancement of the distributed power saving mechanisms of IEEE 802.11 and 802.11e, 802.11 Power Save Mode and U-APSD, when for QoS reasons a delay below the configured beacon interval value has to be provided.

In the area of providing QoS in a wireless LAN a lot of research has been done during the last years, see for example [2], [5]. With respect to the 802.11 power save mode, the infrastructure mode has been studied for instance in [6],[7] where the main focus was to improve the performance for web-like traffic. Regarding U-APSD, in [8] a modified version of the U-APSD functionality (UPSD) based on an 802.11e draft (Dec'04) was studied where the performance of three different UPSD modes was analyzed in a single scenario with 12 stations and two types of traffic, voice and FTP.

In our previous work, we studied in [3] the impact of using the 802.11 power save mode in combination with the 802.11e EDCA QoS mechanisms. In [9] we proposed a MAC power saving algorithm to adaptively control the delay introduced by the 802.11 power save mode for applications requiring QoS guarantees. In [10] we defined a static implementation of U-APSD (SU-APSD) and evaluated its QoS and power saving performance as compared to the 802.11 power save mode. Finally, we designed an adaptive algorithm for U-APSD (AU-APSD) which aims to dynamically configure the SU-APSD algorithm based on the information available at the MAC layer [11]. The paper at hand extends our previous results by proposing a protocol enhancement for 802.11 power save mode and U-APSD that significantly improves their power saving and QoS performance.

The rest of the paper is structured as follows. In Section II a general overview of the U-APSD functionality is given. Section III describes our proposed protocol enhancement, No Data Acknowledgment (NDAck), explaining the reasoning used for its design. The performance improvements obtained as a result of using the NDAck solution in the U-APSD case are provided in Section IV. Finally, Section V summarizes the results and concludes the paper.

II. UNSCHEDULED AUTOMATIC POWER SAVE DELIVERY (U-APSD)

Unscheduled Automatic Power Save Delivery (U-APSD) is the distributed APSD method defined in 802.11e to improve the QoS provided to stations accessing the channel using the EDCA mechanism. The main idea behind the U-APSD design is the usage of data frames sent in the uplink by stations (STA → AP) as indications (*triggers*) of the instants when the power saving stations are awake. When such an indication is received at the AP from a power saving station, the AP takes advantage of it for delivering any data frames buffered while the station was in sleep mode. Because of its specific functionality, this method is specially suited for bi-directional traffic streams even though it provides alternative methods for its usage in other cases. APSD has been designed such that it provides backwards compatibility to legacy terminals implementing the 802.11 power save mode only. Therefore, all new functionality has been built on top of the already available 802.11 power save mode one re-using as much as possible without altering the original power save mode specification. In the following we describe in detail the U-APSD functionality assuming a basic knowledge of the 802.11 power save mode and of the EDCA mechanism of 802.11e. Please see [2] and [3] for an overview of 802.11e and 802.11 power save mode, respectively.

The main difference between the power saving method defined in the 802.11 standard and APSD is that with APSD a station is awake during a Service Period (SP) instead of being awake from the transition to the awake state for receiving a Beacon until the return to the sleep state after acknowledging receipt of the last frame buffered at the AP through PS-Polls.

An *unscheduled SP* begins when the AP receives a *trigger frame*, QoS data or QoS Null, from a station and ends when the station receives a QoS Data or QoS Null frame indicating the end of the service period (EOSP). QoS Null frames are the substitutes in U-APSD of PS-Polls in 802.11 power save mode to allow a station to request the delivery of the frames buffered at the AP even if a station has no data frame to transmit in the uplink. This enables the usage of U-APSD by applications which do not generate uplink traffic often enough to meet the downlink QoS application requirements. Four Access Categories (AC) are defined in EDCA (AC_VO, AC_VI, AC_BE, and AC_BK) corresponding to the applications for which they are intended, i.e., voice, video, best effort and background. Each AC of a station can be configured separately to be delivery/trigger-enabled. When a station has an AC configured as *delivery-enabled*, the AP is allowed to use EDCA to deliver traffic from the AC to a station during an unscheduled SP triggered by a station. When a station AC is *trigger-enabled*, frames of subtype QoS Data and QoS Null from the station, that map to the AC, trigger an unscheduled SP if one is not in progress.

During a SP one or more data frames of delivery-enabled ACs might be delivered by the AP to a station up to the number of frames indicated in the maximum service period length following the rules of an acquired transmission opportunity. The maximum service period length is a field contained in the QoS Info field filled by the station at association. In each directed data or management frame associated with delivery-enabled ACs sent to a station, the More Data (MD) bit indicates that more frames are buffered for the delivery-enabled ACs. For all frames except for the final frame of the SP, the EOSP subfield of the QoS control field of the QoS data frame shall be set to 0 to indicate the continuation of the SP.

In order to guarantee backward compatibility of legacy stations that do not support APSD, the procedure of the AP to assemble the traffic indicator map (TIM) has been modified in such a way that, if at least one of the ACs is non delivery-enabled, it indicates the buffer status *only* of the ACs non delivery-enabled. Note that, in this case, it means that the Beacon will not indicate whether frames of ACs delivery-enabled are buffered. Only in the case that *All* ACs of a station are delivery-enabled the TIM indicates the buffer status of delivery-enabled ACs.

The configuration at the AP of the different ACs per station as delivery/trigger-enabled can be performed either at association time or through the usage of the Traffic Specification element info field (TSPEC) of the Add Traffic Stream frames (ADDTS).

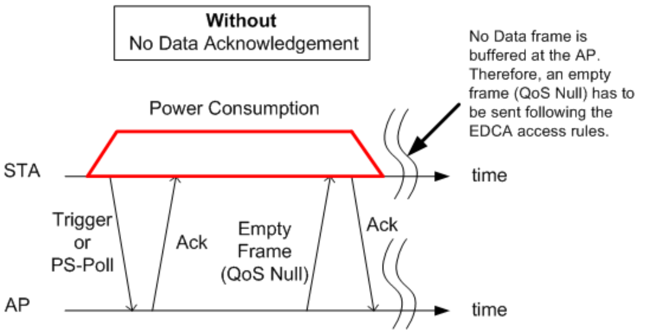

Fig. 1. Message Exchange Without No Data Ack

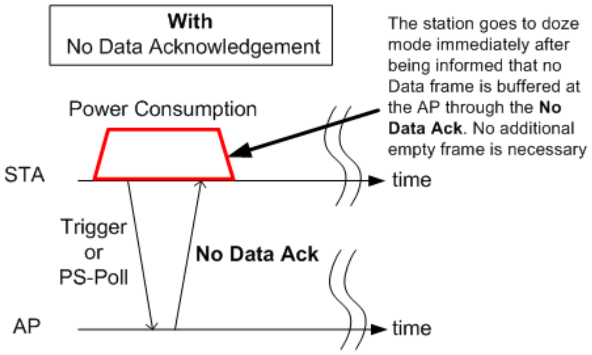

Fig. 2. Message Exchange With No Data Ack

III. No Data Acknowledgment

Depending on the expected delay requirements of an AC with respect to the beacon generation interval of the AP we can differentiate between two cases that require different power saving algorithms. The simplest case is the one where the expected delay requirement of the applications using a certain AC is above the beacon generation interval of the AP. Taking into account that the beacon interval usually configured is 100ms, this would typically be the case of the ACs AC_BE and AC_BK. In this case, the station just needs to set the Listen Interval such that the expected delay requirements of the ACs are fulfilled. By doing this, the default 802.11 power save mode or U-APSD functionality of a station will generate a PS-Poll/QoS Null to retrieve the buffered frames after being informed by the TIM bit in the beacon that frames have been buffered at the AP and thus, the delay requirement of those ACs will be met.

On the other hand, if the expected delay requirements of the applications using a certain AC are below the beacon generation interval of the AP, a way to guarantee that triggers (PS-Polls/QoS Nulls) are generated to meet the delay requirements is needed. Different solutions are possible to limit the MAC downlink delay introduced by 802.11 Power Save Mode or U-APSD (AP → station), static [10] or dynamic [9][11], but in both cases if there is no data buffered at the AP for the station, the AP has to send an empty frame (QoS Null) to indicate to the station that it should go back to doze mode again. This results in an inefficient usage of the scarce resources of the wireless channel and in a waste of the power of the mobile terminal waiting for the empty frame. A typical example of an application that would require a delay smaller than the Beacon interval but would result in wasted resources of the wireless channel is VoIP with silence suppression. See Figure 1 for an illustration of the message exchange.

Our proposed solution to this problem is to use a bit which is not used in the Acknowledgement frames, More Data bit, in order to inform stations as soon as possible of whether they have to wait for a data frame after the reception of the Ack or can go back to doze mode immediately. By doing this, a station that sent a PS-Poll/Trigger can go to doze mode immediately after receiving the acknowledgment if there is no frame buffered at the AP, i.e., reducing in this case the time that a station must remain awake to the minimum. In the rest of the document we will refer to an acknowledgment indicating that no frame is buffered for a certain station as a *No Data Acknowledgment* (NDAck). Figure 2 depicts the message exchange when NDAck is used.

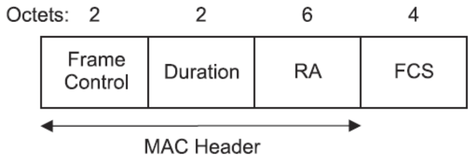

Fig. 3. Acknowledgment Frame Format

The NDAck solution proposes to make use of the More Data bit present in the Ack frames, see Figures 3 and 4, that according to the 802.11 standard is only valid in data or management frames: Section 7.1.3.1.8 *The More Data field is valid in directed data or management type frames transmitted by an AP to an STA in power-save mode*. With our proposal this bit is valid not only in the data and management frames but also in the Ack frames (Control Type) and is used to inform the stations whether they can switch to doze mode directly after receiving the Ack. The usage of this unused bit in the Ack frame enables stations to achieve a larger power saving since they can go to doze mode faster resulting also in a larger capacity of the channel and better QoS experience due to the QoS Null signaling load saved.

The same enhancement can be applied to U-APSD. 802.11e uses the same Ack frame format as 802.11. The usage of its More Data bit though is defined to indicate when a station has frames to be retrieved at the AP (1). However, a zero value does not instruct the stations to go to doze mode when no frame is buffered (0): Section 7.1.3.1.8 *For a non-AP QSTA that has the More Data Ack subfield set in its QoS Capability information element and also has APSD enabled, a QAP may set the More Data field to 1 in ACK frames to this non-AP QSTA to indicate that the QAP has a pending transmission for the non-AP QSTA*. Our proposal would require to modify the stations' behavior defined in the 802.11e standard which only allows a station to go to doze mode once it has received a data frame with the EOSP bit set to true: Section 11.2.1.9 *The non-AP QSTA shall remain awake until it receives a QoS data frame addressed to it, with the EOSP subfield in the QoS Control field set to 1*. Note that, in the particular case where a station has some non delivery-enabled ACs and sends a trigger-enabled frame but no delivery-enabled traffic is buffered, the More Data bit should be set 0

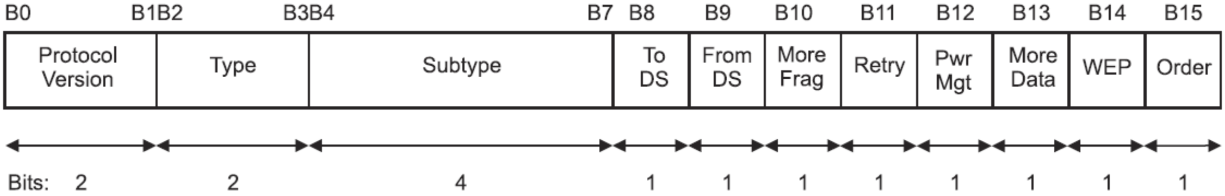

Fig. 4. Frame Control Field Format

to allow to differentiate between this case and the one where delivery-enabled traffic is buffered. We have chosen this option because the NDAck power saving benefit is more important than improving the QoS of non delivery-enabled ACs which do not have stringent QoS requirements. In the next section we study the QoS and power saving improvements that can be achieved by implementing the No Data Acknowledgment functionality.

IV. PERFORMANCE EVALUATION & DISCUSSION

In this section we evaluate our proposed NDAck enhancement by comparing the performance of a generic U-APSD implementation with the performance of a U-APSD implementation that includes the NDAck functionality. The objective of the study is to i) validate the NDAck mechanism proposal and ii) evaluate whether the QoS and power saving performance improvements justify the additional complexity that might be involved on implementing the NDAck functionality in real devices. The analysis is performed via simulation. We extended the 802.11b libraries provided by OPNET 10.5 [12] to include 802.11 power save mode and U-APSD, the required EDCA QoS mechanisms of 802.11e and our proposed NDAck mechanism.

Two different scenarios are considered in the study. The first scenario, *U-APSD*, corresponds to a standard compliant implementation of U-APSD and 802.11 power save mode, where mobile devices running applications with QoS requirements use U-APSD and the rest use 802.11 power save mode. The second scenario, *U-APSD+NDAck*, is the same as the previous one but with the difference that mobile devices running applications with QoS requirements use U-APSD plus the NDAck enhancement and the AP supports NDAck.

The experiment starts with a scenario of one AP and four wireless LAN stations where each station is configured to send and receive traffic from their corresponding pair in the wired domain of its type of application, i.e., one station sends and receives Voice traffic, a second one sends and receives Video traffic, a third one sends and receives Web traffic and a fourth one sends and receives E-mail traffic. The number of stations increases in multiples of four stations always keeping the relation of $1/4$ of stations of each aplication type. All stations operate at a data rate of 11Mbps.

The configuration of the applications used is detailed below:

- Voice: G.711 Voice codec with silence suppression. Data rate: 64kbps. Frame length: 20ms. Talk spurt exponential with mean 0.35s and silence spurt exponential with mean 0.65s.
- Video: MPEG-4 real traces of the movie 'Star Trek: First Contact' obtained from [13]. Target rate: 64kbps. Frame generation interval: 40ms.
- Web: Page interarrival time exponentially distributed with mean 60s. Page size 10KB plus 1 to 5 images of a size uniformly distributed between 10KB and 100KB.
- E-mail: Send interarrival time exponentially distributed with mean 120s. Receive interarrival time exponentially distributed with mean 60s. Size exponentially distributed with mean 100KB.

In both scenarios, *U-APSD* and *U-APSD+NDAck*, the Voice and Video stations are configured to use U-APSD starting service periods at fixed time intervals, every 40 and 60 ms, respectively. Web and E-mail stations use 802.11 power save mode. We have chosen the Service Interval for Voice and Video stations 20ms above the frame generation interval of the traffic sources (20 and 40 ms respectively) to model the fact that, in general, to meet the QoS requirements of the applications it is not necessary to perfectly match their frame generation interval and thus, due to power saving and channel usage efficiency reasons, a larger one is preferable.

Since our focus is on the differences in the performance between using or not NDAck with U-APSD and not on the EDCA parameters configuration, we assume a fixed configuration of the 802.11e EDCA QoS parameters based on the 802.11e standard recommendation [1]. The parameters used are shown in Table I.

	AIFS	CWmin	CWmax
AC_VO	2	31	63
AC_VI	2	63	127
AC_BE	3	127	1023
AC_BK	7	127	1023

TABLE I
EDCA CONFIGURATION FOR THE DIFFERENT ACS

EDCA-TXOP durations are configured to allow the transmission of one data frame after gaining access to the medium (TXOPlimit=0). The RTS/CTS mechanism has not been enabled to avoid its influence over the mechanisms being studied. The Beacon interval used is 100 ms and the listen interval configured for the 802.11 power save mode stations is 1.

The length of the simulations performed is 300 seconds with a warm-up phase of 30 seconds. The number of seeds used to obtain each value in the graphs has been chosen such that the 95% confidence interval of a value in a certain point does not overlap with the 95% confidence interval of any other value.

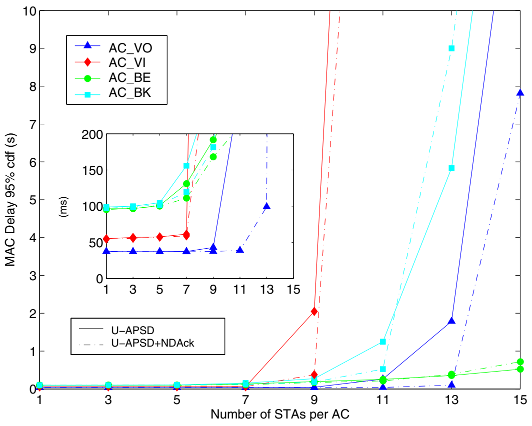

Fig. 5. Impact of the number of stations on the MAC downlink delay

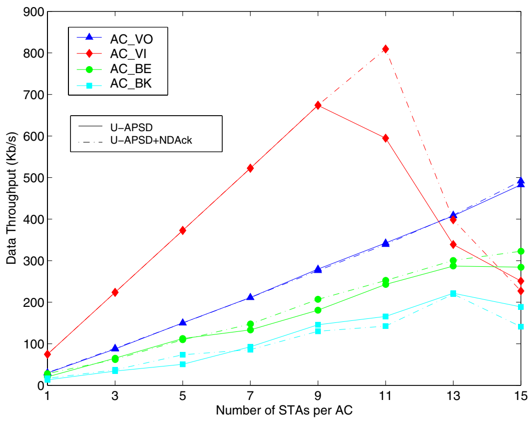

Fig. 6. Impact of the number of stations on the MAC downlink throughput

A. *QoS Differentiation*

Figures 5 and 6 illustrate the impact of increasing the number of stations on the MAC downlink delay and throughput respectively. Only the downlink performance metrics are considered in this section because it is the direction that is most affected by the power saving mechanisms.

If we focus on the delay performance, it can be observed that all stations, independently of the AC used, benefit from the NDAck mechanism until congestion is reached. The performance improvement is specially noticeable for AC_VO stations. The reason for this is the fact that the VoIP codec uses silence suppression. Therefore, when a trigger sent by the wireless station falls within a silence period of its remote partner, the AP does not need to send a QoS Null to end the Service Period resulting in a reduction in the queuing delay of the frames in its AC_VO queue and also in the channel load. As an example, considering a maximum admissible delay for VoIP in the Wireless LAN part of 50ms, the NDAck mechanism would allow to increase the number of admitted voice stations from 9 to 11 in this scenario. With respect to AC_BE and AC_BK stations, although they do not use the NDAck mechanism, their performance is affected by the different amount of load introduced in the channel. These ACs show a better performance in the U-APSD+NDAck scenario until the number of stations of each AC is 11. The reason for a worse performance of these ACs after the 11 stations point in the U-APSD+NDAck case is twofold. First, when the network starts to become congested, the duration of the service periods increases until the U-APSD stations do not send QoS Nulls in the uplink because there is always an ongoing service period. This results in a reduction of congestion in the channel and occurs earlier in the U-APSD case. Second, again in the U-APSD case, the transmission of QoS Nulls instead of Voice frames (larger size) in the downlink reduces the waiting time in the queue for the rest of the ACs. Note that these two effects occur only during a transient phase until the channel is completely saturated and then both U-APSD and U-APSD NDAck achieve the same performance.

The throughput results closely match the delay ones, the most remarkable point is the number of AC_VI stations that can be reached with the NDAck mechanism as compared to without, 11 instead of 9.

B. *Power Saving Efficiency*

The main objective of the NDAck mechanism is to increase the power saving by reducing the duration of the awake periods when the stations have no pending data stored at the AP. In the previous section we have studied the effect of the proposed NDAck mechanism in QoS terms. In this section we study the differences in power consumption between U-APSD and U-APSD+NDAck.

The power saving model used for the evaluation has been derived based on current WLAN cards/chipsets available in the market and consists of four states: Sleep, Listen, Reception and Transmission. The *Clear Channel Assesment* (CCA) function used in our analysis is CCA mode 1, or energy threshold.

Based on this model, we compute the percentage of time spent during an active session in each state by the stations and particularize the results by translating these percentages into *mA* based on the information provided in the product datasheet of a common PCMCIA WLAN card [14]. The power consumption values used are shown in Table II[2].

Cisco Aironet^{TM}	**Sleep**	**Listen**	**Reception**	**Transmission**
Power (mA)	15	203	327	539

TABLE II

POWER CONSUMPTION OF A POPULAR PCMCIA CARD

Figure 7 shows the power spent by the stations for the two power saving methods under study. The power consumption reduction achieved in the U-APSD+NDAck scenario is specially relevant for the VoIP stations (AC_VO), where the results show a power reduction between 7% and 66% depending on the number of stations present in the network. The larger improvement experienced by the AC_VO stations is due to the application used, voice codec with silence suppression. In this case it occurs quite often that a wireless station sends a trigger and no frame is buffered at the AP. The overall signaling load reduction achieved when using the NDAck mechanism results also in a larger power saving for the rest of the stations until congestion is reached.

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[2] For the sleep mode we used the value of a previous model of a Cisco PCMCIA card (Cisco Aironet 350) since no information was available for the current one

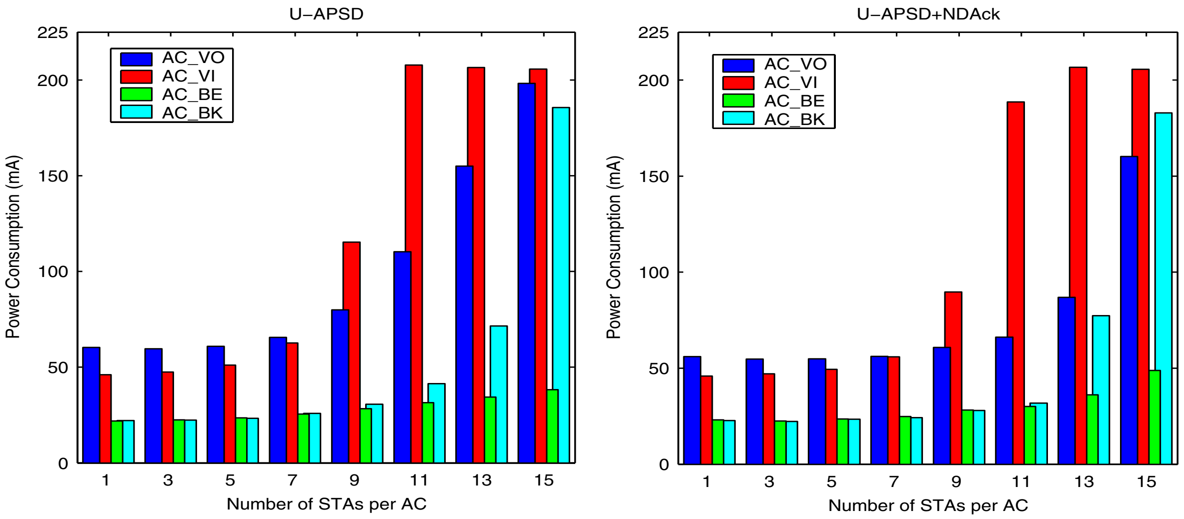

Fig. 7. Impact of the number of stations on the power consumption for *U-APSD* and *U-APSD+NDAck*

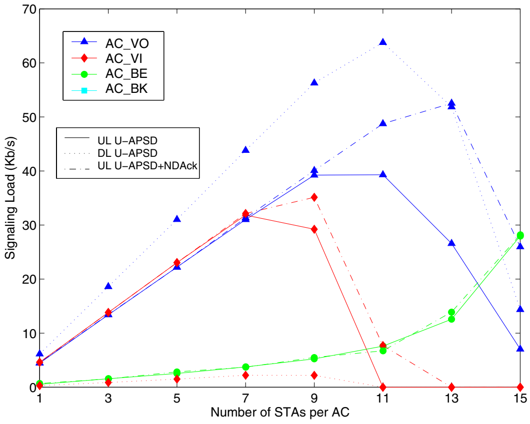

Fig. 8. Impact of the number of stations on the signaling load

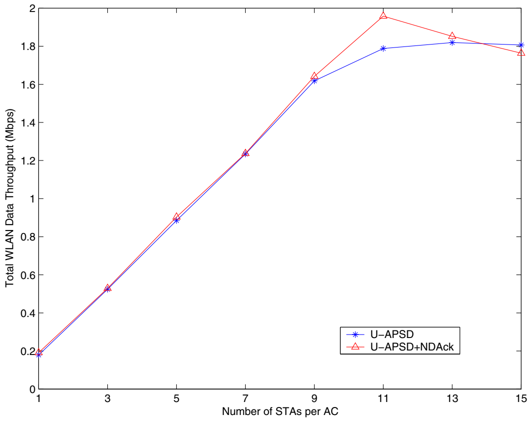

Fig. 9. Impact of the number of stations on the total channel capacity

C. *Channel Usage Efficiency*

In this section we evaluate which are the improvements obtained with the proposed NDAck mechanism in terms of signaling load and maximum data throughput. Figure 8 shows the signaling load introduced by the different stations both in uplink and downlink grouped by the AC used to transmit the frames. Note that in the downlink there is no signaling load generated in the U-APSD+NDAck case since no QoS Nulls need to be transmitted. Additionally, according to the 802.11e standard recommendation, PS-Polls generated by the AC_BE and AC_BK stations have been transmitted using the AC_BE access category.

From the figure, it can be observed that with the NDAck mechanism the AC_VO and AC_VI signaling load in the downlink has been removed. This result is as expected since no signaling load is introduced by the AP in order to end service periods when no data frames are buffered. Regarding the uplink AC_VO and AC_VI signaling load, saturation is reached later in the U-APSD+NDAck case since, as explained in Section IV-A, the duration of the SPs is shorter. With respect to AC_BE and AC_BK, as expected the NDAck mechanism does not impact the signaling introduced since no changes have been made.

The total data throughput in the Wireless LAN channel is shown in Figure 9. The results show that the NDAck mechanism allows to admit in this particular scenario 2 additional stations of each AC (8 in total) as compared to the case where NDAck is not used before data frames start to get dropped. These results match with the data throughput AC_VI ones presented in Section IV-A.

V. SUMMARY & CONCLUSIONS

Mobile devices including Wireless LAN capabilities are expected to meet two main requirements in order to fulfill users' expectations: QoS support for differentiating real-time services from non real-time and power saving functionality to achieve a reasonable operating time. Our work in this paper has focused on the design and evaluation of a protocol enhancement of the Wireless LAN distributed power saving mechanisms, 802.11 power save mode and 802.11e U-APSD, in order to increase the battery lifetime of Wireless LAN mobile devices while providing the required QoS. The protocol improvement designed has been implemented in OPNET to evaluate the performance enhancements obtained. The main conclusions that can be drawn from our results are i) NDAck significantly reduces the power consumption of stations running real-time applications, ii) the larger the power consumption due to the congestion in the wireless channel the larger the power consumption reduction with NDAck and iii) NDAck results in a considerable QoS improvement for real-time applications. Specifically, the improvements obtained with NDAck in the considered scenario for VoIP stations considering a maximum delay for the WLAN part of 50ms are:

VoIP STAs	**Num. Users**	**Power Saving**	**Sign. Load**
U-APSD+NDAck	22%	7% - 66%	60% - 70%

TABLE III

WIRELESS LAN NETWORK PERFORMANCE IMPROVEMENT FOR VOIP STATIONS

VI. ACKNOWLEDGMENTS

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