An Energy-efficient MAC layer Scheme for 802.11-based WLANs*

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Abstract

This paper focuses on energy saving in 802.11-based WLANs. Typically, 802.11 wireless interfaces consume a significant amount of energy. Previous work has shown that the power saving function specified in the IEEE 802.11 standard is not enough to ensure energy efficiency; thus, other solutions to energy saving are highly needed. Here we consider the 802.11 distributed access scheme and explore the possibility to increase the time period that a wireless station spends in the low-power operational state, the so-called doze state. The key feature of the proposed mechanism is that it enables a station to enter the doze state during channel contention, by exploiting the virtual carrier sense mechanism and the backoff function. By using the network simulator ns-2, we compare the performance obtained through our scheme with the results attained when the standard DCF mechanism is employed.

1 Introduction

Currently, Wireless Local Area Networks (WLANs) based on the IEEE 802.11 standard [1] are one of the most successful technologies, since they support both user mobility and high data rates. The most popular and widely-deployed 802.11 network configuration includes an Access Point (AP) and several wireless stations (WSTAs); the AP provides connectivity with the wired part of the network thus allowing Internet services to be extended to wireless users. The AP along with the WSTAs connected to it constitute the so-called Basic Service Set (BSS).

Several heterogeneous wireless devices may be part of a BSS, ranging from high performance laptops to small pagers. However, for all kinds of 802.11 devices, energy consumption is a critical issue [2, 3, 4].

An 802.11 wireless interface can be in one of the following states while being on: transmitting state, receiving state, idle state (i.e., when the channel is sensed without actively receiving), and doze state (i.e., when the radio tranceiver is turned off). Different operational states correspond to different values of power consumption. In [4, 5], it is reported that Lucent IEEE 802.11 WaveLan cards consume 1.65W, 1.4W, 1.15W and 0.045W in the four operational states, respectively; thus, an 802.11 interface consumes a significant amount of power, even in idle state. This is a key point to energy saving, since the standard 802.11 distributed access scheme, the so-called Distributed Coordination Function (DCF), is based on the CSMA/CA mechanism and requires a WSTA to continuously sense the channel. As a consequence, a WSTA spends a significant amount of time in idle state and typically experiences a high energy expenditure even if it does not transmit or receive any data. These considerations suggest that, in order to save energy, it is mandatory to reduce the time spent by a WSTA in idle mode and increase the time it spends in doze mode.

The IEEE 802.11 standard specifies a Power Management (PM) function, which allows a WSTA to switch to the doze mode whenever the wireless interface is idle [1]. Some studies [4, 6], however, have shown that the 802.11 PM scheme presents several inefficiencies. Other solutions to energy saving in 802.11 WLANs can be found in [4, 6, 7, 8, 9, 10, 11, 12] (please see Section 2 for further details on the related work).

In this paper, we present an energy-efficient technique at the MAC layer, called the *Energy-efficient Distributed Access (EDA)* scheme. The EDA mechanism is based on the 802.11 DCF and aims at reducing

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the channel-sensing activity of the WSTAs in favor of the time they can spend in doze mode. Our technique differs from the 802.11 PM mode in that EDA allows WSTAs to enter the doze state while participating in the network activity.

Clearly, there exists a trade-off between energy saving on the one hand, and traffic delivery delay and collision probability on the other hand. We therefore study the performance of the EDA scheme considering both uplink and downlink traffic flows, and we compare the performance of EDA with the results obtained through the standard DCF. The study is performed by using the network simulator *ns-2* [13].

We would like to highlight that the EDA scheme significantly improves our earlier work on energy saving in 802.11 WLANs [14], by greatly reducing the average delivery delay of data traffic, as well as the collision probability over the wireless channel. Furthermore, although we do not consider the 802.11 PM here, we point out that the EDA technique can be used jointly with the PM function.

The remainder of the paper is organized as follows. In Section 2 we review some previous work on energy efficiency in WLANs. We present the network scenario under study in Section 3. Section 4 briefly describes the 802.11 DCF scheme, while Section 5 introduces the proposed energy-efficient technique. We show some performance results comparing the EDA technique to the standard DCF in Section 6.

2 Related Work

Several papers have addressed the issue of energy efficiency in wireless local area networks.

In [7] the authors present the so-called PAMAS scheme, where each node uses two separate channels, one for control and the other for data packet transmissions. Power saving is achieved by turning off the network interface of a node whenever it does not need to transmit nor receive.

The works in [4, 6] focus on analysis and enhancements of the IEEE 802.11 PM [1]. In [6] the authors observe the 802.11 PM inefficiency due to the fixed beacon interval duration and show that the 802.11 PM is not an efficient solution to power saving under low traffic load. To overcome this problem, the work in [4] proposes an adaptive mechanism to dynamically adjust the ATIM window size according to the network load. To avoid the overhead, as well as the bandwidth and energy waste, due to the ATIM window, the authors also suggest the use of a DATA window, during which data can be exchanged directly between the WLAN nodes.

In [8], a distributed mechanism for power saving is proposed that enables each station to estimate the channel utilization during a backoff period and to compute the probability to transmit successfully. If such a probability is low, the station defers its access attempt. In this way energy waste due to failed transmissions is reduced. The work in [9] presents an analytical framework to calculate the appropriate value of the average contention window to be used in IEEE 802.11 WLANs so as to maximize the system throughput and minimize the energy consumption.

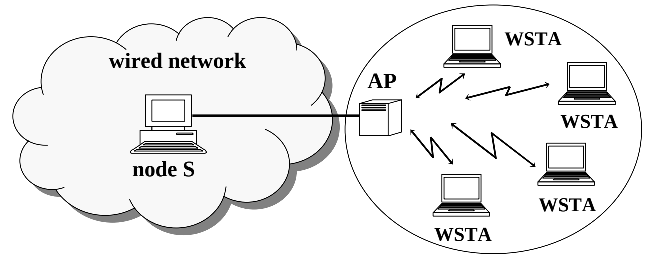

Figure 1: Network scenario under study

The mathematical framework in [10] evaluates the power dissipation at the 802.11 MAC layer due to data transfer. It also proposes a load sharing algorithm aiming at adjusting the load among different WLAN areas so that collisions are reduced.

The works in [11, 12] act on different 802.11 system parameters with the aim to reduce power consumption. In [11] the impact of the RTS (Request-To-Send) Threshold on energy consumption is studied, and an algorithm to adaptively change this parameter is proposed. In [12] the authors present a scheme to select the node transmission rate, which minimizes the average waiting time of each transmission and, hence, reduces energy consumption.

3 Network System

We consider a wireless-cum-wired network scenario as shown in Figure 1. The wireless portion of the network is an 802.11b-based WLAN including an AP and several stationary WSTAs. A fixed node S is connected with the AP through a wired link, which is over-provisioned so that no packets are dropped at its ends. The RTS/CTS (Ready-To-Send/Clear-To-Send) mechanism is employed. Also, we assume that WSTAs and AP always operate at a transmission rate of 11 Mbps.

At transport layer, UDP flows are established between each WS and the fixed node S. In particular, while deriving the performance results, we focus on two traffic scenarios: in the former all traffic flows are established on the uplink direction (from a WSTA to

S), in the latter all flows are on the downlink direction.

With regard to the wireless channel behavior, we consider an independent error model for each communicating pair of nodes. The error model is represented by a three-state discrete-time Markov chain. The Markov chain time slot is equal to the 802.11b time slot duration (namely, $20\mu s$). Errors over the channel occur in the states *Long Bad (LB)* and *Short Bad (SB)*, while the *Good (G)* state is error-free. Thus, a frame transmission is successful only if the error model is in state G for all slots it takes the frame to be transmitted, while it fails otherwise. The difference between the LB and the SB state is the time correlation of errors: LB corresponds to long bursts of errors, SB to short ones. The probability that the Markov chain moves to the LB state given that it leaves the state G, i.e., the probability that an error burst is long, is set to 0.05. We assume that the average time duration of a burst of bad slots experienced when the states LB and SB are entered, are respectively equal to 1 s and 0.04 s. The average number of consecutive slots in state G is set to 1.672 s.

4 The IEEE 802.11b Standard Access Scheme

In this section we briefly describe the IEEE 802.11 DCF [1].

The DCF exploits both a physical and a virtual channel sensing. Virtual sensing is implemented by including in all transmitted frames an indication of their duration so that the non-destination 802.11b nodes overhearing a transmission can set their NAV accordingly. Once a node has set its NAV, it is in idle state [2]. When a node has to transmit a frame, the physical and virtual carrier sense mechanisms are checked. If within an interval of DIFS (or EIFS if the previous frame was received in error) either the physical or virtual carrier sense mechanisms detect the channel as busy, the WSTA selects a backoff interval from a range of values called Contention Window (CW) and sets its backoff counter to this time interval. The backoff counter is decremented only during idle channel periods. Again, an 802.11b node can be considered as in idle state during the backoff time. When a node gains access to the channel and transmits a data frame successfully, it will receive an acknowledgment message (ACK) from the receiver after a time interval equal to SIFS (with SIFS shorter than DIFS).

The AP periodically seizes the channel to send a Beacon frame including various control information. A Beacon frame is supposed to be transmitted at a predefined time instant called Target Beacon Transmission Time (TBTT). The AP can seize the channel after it has sensed the wireless medium as idle for an interval equal to PIFS (with PIFS longer than SIFS and shorter than DIFS).

In the following, we will compare the performance of our energy-efficient technique against the case where the standard DCF scheme is employed.

5 The EDA Technique

Consider a BSS where the AP and the WSTAs access the channel using the standard DCF. Since the DCF requires WSTAs to sense the channel at all times in order to avoid collisions, a WSTA will end up spending a large amount of time in the idle state.

Our first objective in developing an energy-efficient technique is to *convert* the time spent by a WSTA in idle state into time spent in doze state. Our second objective is to limit as much as possible the degradation of the system performance in terms of traffic delivery delay, which typically occurs when an energy-saving mechanism is employed.

The EDA scheme involves a slight modification of the following two aspects of the DCF protocol: (i) the virtual sensing mechanism and (ii) the backoff procedure. All other mechanisms are unchanged with respect to the 802.11 DCF.

According to the EDA scheme, a WSTA behaves as follows. When the WSTA wishes to transmit, it listens to the channel for a period of DIFS duration. If it detects the channel as busy, the WSTA extracts a backoff value and enters the doze mode, turning off its tranceiver. While being in the doze mode, the backoff counter is decremented continuously till it reaches zero. It is clear that, during its backoff period, the WSTA is not aware of the traffic activity over the channel, thus the WSTA does not set the NAV during the backoff period and the backoff counter is never frozen. When the backoff counter expires, the WSTA does not immediately transmit but first listens to the channel for a period of PIFS duration. If the channel is sensed as busy, the WSTA doubles its CW size and extracts a new backoff value.

Note that sensing the channel for a PIFS time ensures the WSTA a certain priority with respect to those WSTAs that are attempting a channel access for the first time (recall that these WSTAs have to sense the channel for DIFS that is longer than PIFS). Furthermore, using PIFS allows the WSTAs to reduce the probability that their transmission will collide with an ACK frame (recall that an ACK is sent by a receiver after a time SIFS from the end of a data reception). Finally, the use of the interval PIFS never causes the WSTA transmissions to overlap with the Beacon frame sent by the AP, assuming that the

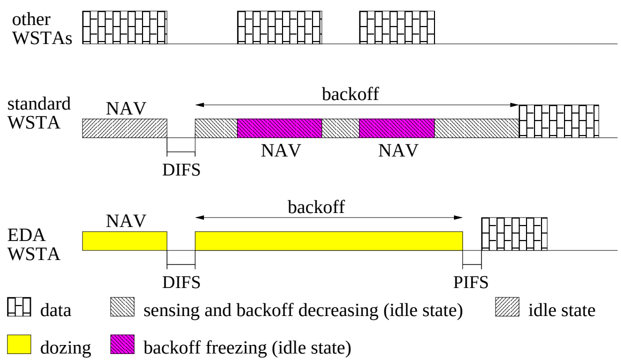

Figure 2: Comparison between the behavior of a WSTA under the standard DCF and under the EDA scheme

WSTAs refrain from starting any transmission that would occupy the channel in correspondence of the time instant TBTT[1].

Figure 2 shows an example of how the EDA scheme works. The figure compares the different behavior of a WSTA when it operates under the standard DCF and when it uses the EDA mechanism. On the top of the figure, the transmissions of other WSTAs over the wireless channel are represented. According to both the standard and the EDA scheme, the considered WSTA computes a backoff interval after having sensed the channel idle for DIFS. However, while in the standard case the backoff is frozen whenever the channel is busy, under the EDA scheme, the WSTA decrements the backoff continuously being in the doze state. When the backoff reaches zero, in the case of the standard DCF, the WSTA immediately transmits. On the contrary, under EDA, the WSTA senses the channel for a time equal to PIFS and only if the channel is detected as idle, the WSTA transmits its frame.

6 Numerical Results

We study the system performance via simulation using the network simulator *ns-2* [13]. Two different simulation scenarios are considered. In the first scenario every WSTA is involved in an uplink traffic flow toward the AP, in the second one the AP transmits on the downlink direction to every WSTA within the BSS. The traffic offered to the network is generated by UDP flows exhibiting an *on-off* behavior. During *off* periods no traffic is generated; the average duration of the *off* period, denoted by T_{off}, is taken as a constant parameter and is set to 1 s. On the contrary, during *on* periods, the WSTA generates traffic at a constant rate of 256 kbit/s. The average duration of the *on* period, denoted by T_{on}, is a configurable parameter that we vary in our simulations. Thus, we can act on the system load by tuning the value of the *on* period as well as the number of WSTAs in the BSS.

[1] All WSTAs within a BSS compute the TBTT, i.e., the time instant at which the AP will send the next Beacon frame. The fact that WSTAs must refrain from transmitting in correspondence of the TBTT is already specified in [15].

Table 1: 802.11 Parameter Setting

CW_{min} (std., EDA)	31
CW_{max} (std., EDA)	1023
CW_{min} (large EDA)	63
CW_{max} (large EDA)	2047
RTS Threshold	400 bytes
Slot time	$20\mu s$
SIFS time	$10\mu s$
DIFS time	$50\mu s$
EIFS	$60\mu s$
Short Retry Limit	20
Long Retry Limit	10
Preamble Length	144 bits
PCLP length	48 bits
ACK Frame Length	112 bits
UDP payload	8000 bits

The wireless channel is modeled as described in Section 3, while the 802.11 parameter setting that we adopt is presented in Table 1. As reported in Table 1, we present the performance of the EDA scheme for two different settings of the CW size: CW_{min}=31 and CW_{max}=1023 (i.e., the same as the one used in the standard DCF), and CW_{min}=63 and CW_{max}=2047. In the following plots, the curves referring to the case where the larger CW size values are used are labeled as "EDA large CW." The parameters Short Retry Limit and Long Retry Limit are set to 20 and 10, respectively. The payload length is constant and fixed to 1000 bytes. The other parameters are set as specified in the 802.11 standard.

The WSTA power consumption in the different operational states are set as follows: P_{tx}=1.65 W, P_{rx}=1.4 W, P_{idle}=1.15 W, and P_{doze}=0.045 W.

In order to evaluate the system performance when the EDA algorithm is applied, we consider the following metrics: (i) the average energy consumption per successful packet, i.e., the ratio of the total energy expenditure of a WSTA to the number of packets that are successfully delivered at the AP, in the case of uplink flows, or at the WSTAs, in the case of downlink flows, (ii) the average packet delivery delay, computed as the sum of the queueing delay and the service de-

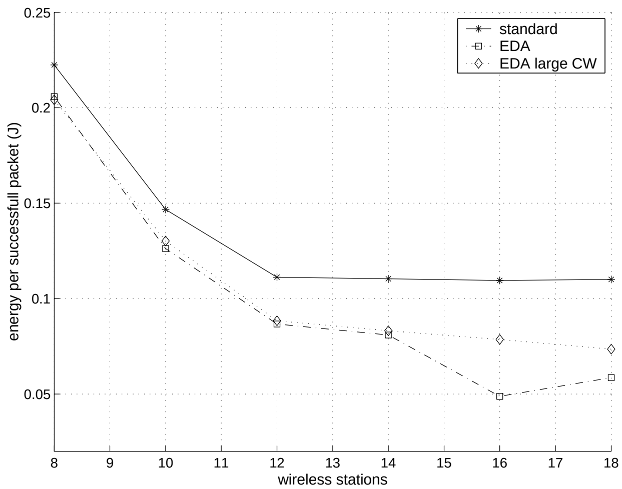

Figure 3: Average energy consumption per successful packet versus the number of wireless stations, when $T_{on} = 0.5$ s and $T_{off} = 1$ s. The performance of the EDA scheme with different CW size and of the standard function are compared under the uplink traffic scenario

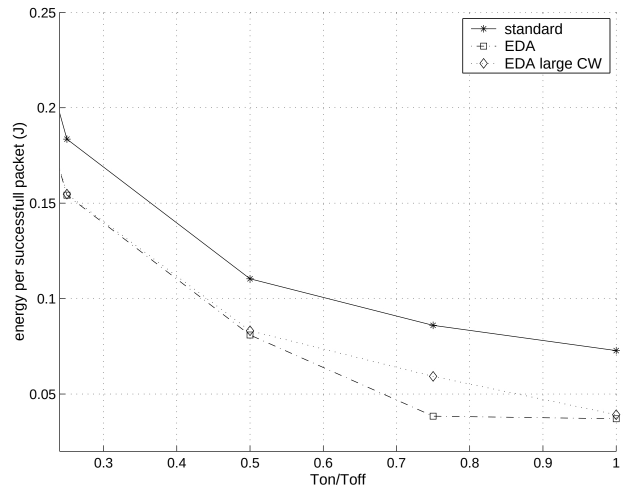

Figure 4: Average energy consumption per successful packet versus the ratio T_{on}/T_{off}, when $T_{off} = 1$ s and the number of WSTAs in the system is equal to 14. The performance of the EDA scheme with different CW size and of the standard function are compared under the uplink traffic scenario

lay at the MAC layer, (iii) the collision probability over the wireless channel, and (iv) the packet dropping probability due to the fact that the maximum number of allowed transmission attempts at the MAC layer has been reached. The results obtained through the EDA scheme are compared to the performance of the standard DCF (labeled by "standard" in the plots).

The first set of figures (Figures 3–7) present the results derived under the uplink traffic scenario, while the second set (Figures 8–10) refer to the downlink traffic scenario.

Figure 3 presents the energy consumption per successful packet under the uplink traffic scenario, as a function of the number of WSTAs in the network. The improvement in the case of EDA relatively to the standard case is quite relevant and becomes more evident as the number of WSTAs grows. This is because an increase in the number of WSTAs corresponds to an increase in the traffic load. As the channel load grows, the WSTAs spend more time in backoff mode and, thanks to EDA, they can spend more time in doze mode. Thus, these results suggest that the EDA scheme works very efficiently, significantly outperforming the standard scheme, under medium-high traffic conditions.

The behavior shown in Figure 3 can be also observed in Figure 4. Here, we consider 14 WSTAs and we vary the average duration of the *on* period of the

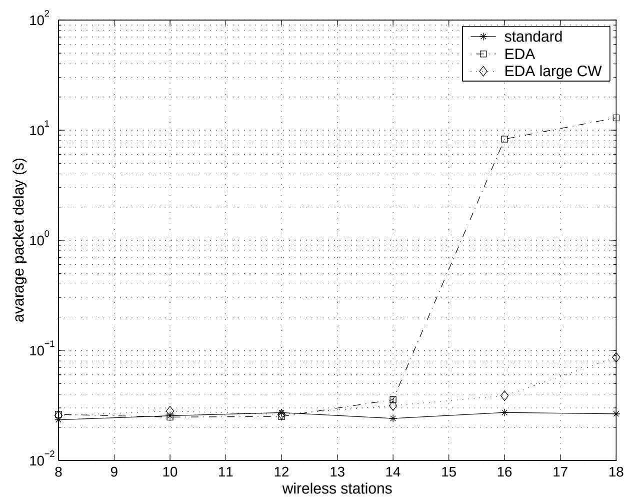

Figure 5: Average packet delay as a function of the number of wireless stations, when $T_{on} = 0.5$ s and $T_{off} = 1$ s. The performance of the EDA scheme with different CW size and of the standard function are compared under the uplink traffic scenario

traffic sources (T_{off} is set to 1 s). When the ratio T_{on}/T_{off} is equal to 0.25, the total offered traffic is equal to 716.8 kbps. When the ratio T_{on}/T_{off} is equal to 1, the total offered load is of 1.792 Mbps, while the channel utilization, computed as the total time during which the radio channel is busy divided by the simulation duration, is about 72%. Note that such a high channel utilization is caused by the frequent retransmissions due to channel errors.

Figure 4 shows that the energy consumption per successful packet decreases as the ratio T_{on}/T_{off} increases. Indeed, as the duration of the *on* period increases, the time spent in idle mode by a WSTA becomes shorter. This suggests that the contribution of the idle state to energy consumption is significant, also when the EDA technique is used, and that combining the EDA scheme with the 802.11 PM could result in further improvements in energy saving. Also, from Figure 4 we observe again a significant reduction in energy consumption under the EDA scheme, relatively to the standard case; this reduction becomes more evident as the traffic load increases.

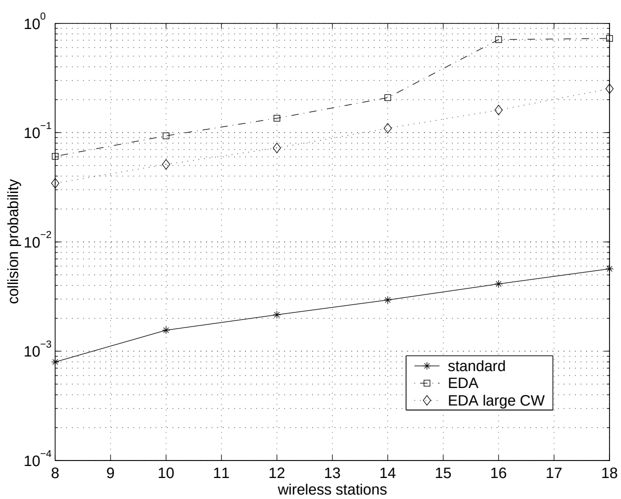

Figure 6: Collision Probability as a function of the number of wireless stations, when $T_{on} = 0.5$ s and $T_{off} = 1$ s. The performance of the EDA scheme with different CW size and of the standard function are compared under the uplink traffic scenario

Figure 5 presents the average packet delay as the number of WSTAs varies. When a small number of WSTA is considered, the values of delay obtained with the EDA and the standard scheme are quite close. As the number of WSTA grows, the DCF function outperforms the EDA scheme. This was expected, since energy saving mechanisms make wireless devices become less reactive to the network activity and to the changes over the wireless channel, increasing the collision probability and, hence, the delay. However, the performance gap between EDA and the standard access function is much less evident in the 'EDA large CW' case. In fact, when several WSTAs contend for the channel, using a larger size of the CW significantly reduces the collision probability. This phenomenon is confirmed by the behavior of the collision probability versus the number of WSTAs, that is shown in Figure 6.

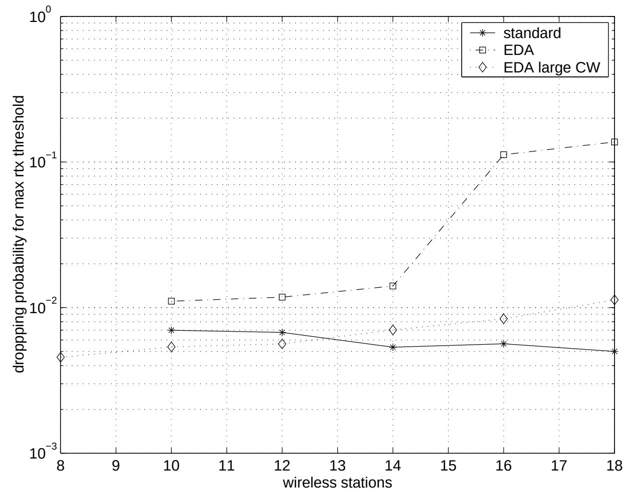

Figure 7: Dropping Probability for exceeding the maximum retransmission threshold as a function of the number of wireless stations, when $T_{on} = 0.5$ s and $T_{off} = 1$ s. The performance of the EDA scheme with different CW size and of the standard function are compared under the uplink traffic scenario

Figure 7 presents the probability to drop a packet that has exceeded the maximum number of transmission attempts. Interestingly, we observe that the benefit of reducing the number of packet collisions by enlarging the CW size in the EDA scheme is evident also in this plot. Although the standard scheme again outperforms EDA, the results obtained in the 'EDA large CW' case are quite close to the standard scheme performance.

Next, we present the results derived under the downlink traffic scenario.

Figure 8 presents the average energy consumption per successful packet versus the number of WSTAs, when the ratio T_{on}/T_{off} is set to 0.5. Figure 9 shows the same performance metric as a function of the ratio T_{on}/T_{off}, when the number of WSTAs is set to 10. (Note that when $T_{on}/T_{off} = 0.25$, the total traffic offered to the network is equal to 512 kbps, while when $T_{on}/T_{off} = 2$, the total offered load is 1.706 Mbps.) The behavior that we obtain is similar to the one observed under the uplink traffic scenario, thus showing that the EDA algorithm gives excellent performances

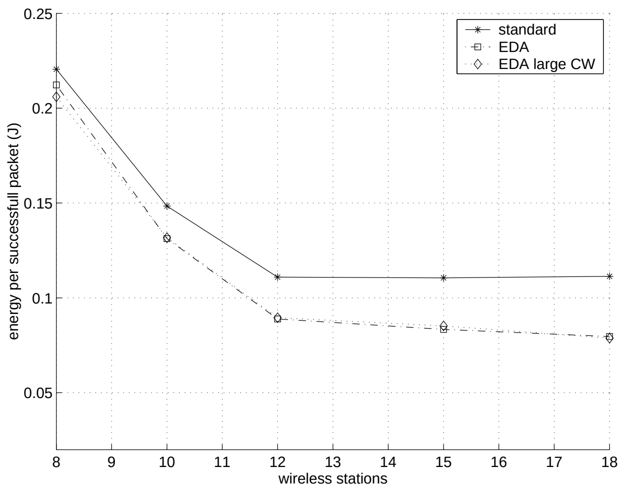

Figure 8: Average energy consumption per successful packet versus the number of wireless stations, when $T_{on} = 0.5$ s and $T_{off} = 1$ s. The performance of the EDA scheme with different CW size and of the standard function are compared under the downlink traffic scenario

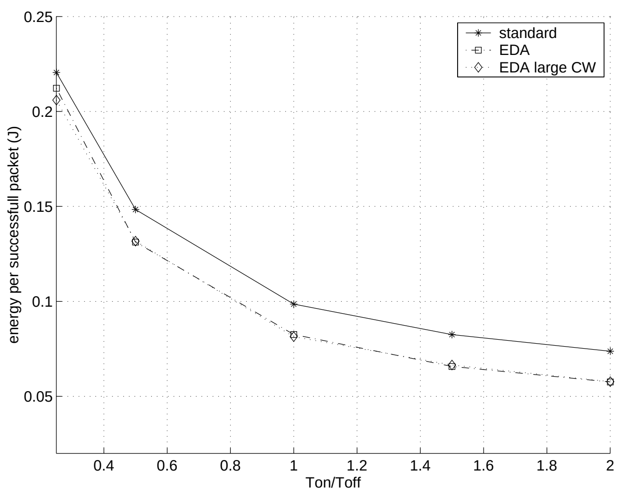

Figure 9: Average energy consumption per successful packet versus the ratio T_{on}/T_{off}, when $T_{off} = 1$ s and the number of WSTAs in the system is equal to 10. The performance of the EDA scheme with different CW size and of the standard function are compared under the downlink traffic scenario

also when downlink traffic flows are considered.

Finally, Figure 10 presents the average delivery delay per successful packet as the number of WSTAs varies. In this case the EDA scheme with a larger CW size gives worse performance than both the standard scheme and EDA with smaller values of the CW setting. In fact, in the downlink traffic scenario only the AP transmits, so there is no need to enlarge the CW to reduce collisions. The only effect that we obtain enlarging the CW size is an increase in the traffic delivery delay.

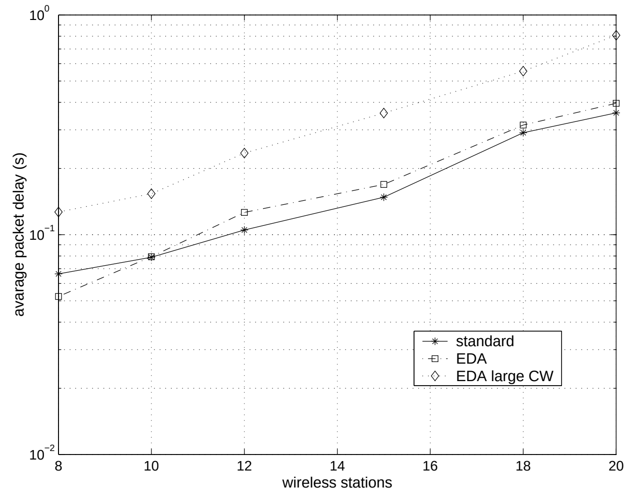

Figure 10: Average packet delay as a function of the number of wireless stations, for $T_{on} = 0.5$ s and $T_{off} = 1$ s. The performance of the EDA scheme with different CW size and of the standard function are compared under the downlink traffic scenario

7 Conclusions and Future Work

In this paper we focused on energy efficiency in WLANs. We proposed an energy-saving, MAC-layer technique which is based on the 802.11 DCF scheme. The proposed mechanism allows a wireless station to enter the low-power operational state, the so-called *doze* state, while it participates in the WLAN activity and contend for the channel. By using the *ns-2* simulator, we studied the system performance in terms of energy consumption and traffic delivery delay, for both uplink and downlink traffic flows. We compared the results obtained through our scheme with the system performance obtained when the standard DCF is employed. The results show that our scheme significantly reduces energy consumption, while maintaining the increase in traffic delay small.

Future work will study the performance of the proposed scheme under more complex traffic scenarios and in the presence of TCP traffic flows. It will also focus on the integration of the proposed scheme with the 802.11 power saving function and will investigate the synergies between the two mechanisms.

References

[1] IEEE 802.11 WG, *Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications*, 1999.

[2] L. M. Feeney and M. Nilsson, "Investigating the Energy Consumption of a Wireless Network Interface in an Ad Hoc Networking Environment," *IEEE INFOCOM 2001*, Anchorage, AK, Apr. 2001, pp. 1548–57.

[3] J.-P. Ebert, B. Burns, and A. Wolisz, "A Trace-based Approach Determining the Energy Consumption of a WLAN Network Interface," *European Wireless 2002,*, Feb. 2002, pp. 230–236.

[4] E.-S. Jung and N. H. Vaidya, "An energy efficient MAC protocol for wireless LANs," *IEEE INFOCOM 2002*, New York, NY, June 2002, pp. 1756–64.

[5] A. Kamerman and L. Monteban, "WaveLAN-II: A High Performance Wireless LAN for the unlicensed band," *Bell Labs Technical Journal,* Vol. 2, No. 3, 1997.

[6] J.-M. Choi, Y.-B. Ko, and J.-H. Kim "Enhanced Power Saving Scheme for IEEE 802.11 DCF Based Wireless Networks," *International Conference on Personal Wireless Communication (PWC '03)*, Venice, Italy, Sep. 2003, pp. 835–840.

[7] S. Singh and C. S. Raghavendra, "PAMAS - Power Aware Multi-Access protocol with Signaling for Ad Hoc Networks," *ACM Computer Communication Review*, Vol. 28, No. 3, 1998, pp. 5-26.

[8] L. Bononi, M. Conti, and L. Donatiello, "A Distributed Mechanism for Power Saving in IEEE 802.11 Wireless LANs," *ACM/Baltzer Mobile Networks and Applications (MONET)*, Vol. 6, No. 3, June 2001, pp. 211–22.

[9] R. Bruno, M. Conti, and E. Gregori "Optimization of Efficiency and Energy Consumption in p-Persistent CSMA-Based Wireless LANs," *IEEE Transactions on Mobile Computing* ,Vol. 1, No. 1, Jan. 2002, pp. 10–31.

[10] I. B. Dhaou, "A Novel Load-Sharing Algorithm for Energy Efficient MAC Protocol Compliant with 802.11 WLAN," *IEEE Vehicular Technology Conference (VTC-Fall) 1999*, Amsterdam, Netherlands, Sep. 1999, pp. 1238–42.

[11] S. Yan, Y. Zhuo, and S. Wu, "An Adaptive RTS Threshold Adjust Algorithm based on Minimum Energy Consumption in IEEE 802.11 DCF," *ICCT 2003*, Beijing, China, Apr. 2003, pp. 1210–14.

[12] C.-S. Hsu, J.-P. Sheu, and Y.-C.Tseng, "Minimize Waiting Time and Conserve Energy by Scheduling Transmissions in IEEE 802.11-based Ad Hoc Networks," *International Conference on Telecommunications (ICT) 2003*, Papete, French Polynesia, Feb 2003, pp. 393–399.

[13] UCB/LBNL/VINT, "Network Simulator – ns – version 2.26, URL: http://www.isi.edu/nsnam/ns, 2002.

[14] V. Baiamonte and C. F. Chiasserini, "Investigating MAC-layer Schemes to Promote Doze Mode in 802.11-based WLANs," *IEEE Vehicular Technology Conference, VTC 2003 - Fall*, Orlando, FL, Oct. 2003.

[15] IEEE 802.11 WG, Draft Supplement to Standard for Telecommunications and Information Exchange Between Systems-LAN/MAN Specific Requirements - Part 11: Wireless Medium Access Control (MAC) and physical layer (PHY) specifications: Medium Access Control (MAC) Enhancements for Quality of Service (QoS), IEEE 802.11e/Draft 5.0, July 2003.