Greening IEEE 802.11 channel access

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***Abstract*—Energy consumption in the wireless channel access protocols is a key factor to take into account in the design of future telecommunication infrastructures. This extended abstract introduces an overview of our work on the relation between energy efficiency and throughput optimization, and the need for a criterion that balances both objectives.**

I. INTRODUCTION

Communication protocols, and in particular the technologies used in the access network, have been originally conceived to optimize metrics other than energy, such as throughput or delay. *Greening* these protocols thus represents a shift in the design paradigm, where energy instead of time is the most critical network resource. We no longer want to maximize the bits sent per time unit, but instead the bits the network can send per each joule consumed. Still, it is intuitively clear that this will not come for free, and there might be a price to pay in terms of throughput performance when developing sustainable and energy efficient architectures.

II. HOMOGENEOUS SCENARIO

Table I
POWER CONSUMPTION PARAMETERS WHILE TRANSMITTING (ρ_t), RECEIVING (ρ_r) AND IDLING (ρ_i) (IN WATTS)

#	Card	ρ_t	ρ_r	ρ_i
A	Lucent WaveLan	1.650	1.400	1.150
B	SoketCom CF	0.924	0.594	0.066
C	Intel PRO 2200	1.450	0.850	0.080

We first consider [1] an homogeneous WLAN where all stations use the same power properties. Our analytical model for the energy consumption in such a scenario requires the following input parameters: N, the number of stations in the WLAN; CW_{min}, defined as the minimum contention window stations use on their first transmission attempt; and ρ^{tx}, ρ^{rx} and ρ^{id}, defined as the power consumed by the wireless interfaces when transmitting, receiving and idling, respectively. We assume all stations have always a packet of fixed length L ready for transmission. We also define energy efficiency (η) as the ratio between throughput and energy consumption.

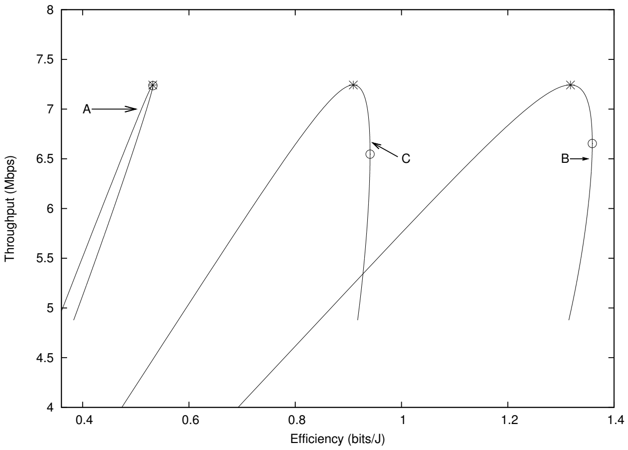

Figure 1. Trade-off imposed by the energy features of the WLAN interfaces

Our findings are summarized in Fig. 1. In this figure, we plot for the case of $N = 10$ the resulting values of the energy efficiency (in the x-axis) and throughput (in the y-axis) for all possible configurations of the CW parameter and all the interfaces of Table I). In the figure, we mark with a star the point of maximum throughput performance, and with a circle the point of maximum energy efficiency.

These results confirm that there is a trade-off between energy and throughput maximization that depends on the characteristics of the WLAN interface. Indeed, for some figures of power consumption we find that both throughput and energy efficiency can be simultaneously maximized. However, our results show also that, for existing WLAN interfaces, this is not always the case and therefore, *these two performance parameters, throughput and energy efficiency, do indeed constitute different objectives*.

III. HETEROGENEOUS SCENARIO

One key limitation of the previous approach is that it only considers homogeneous scenarios. This actually constitutes a non-realistic scenario as, indeed, WLAN devices show very different power consumption figures (see Table I). We argue [2] that any configuration that aims at optimizing the energy efficiency of a wireless network needs to take into account the diversity of the power consumption interfaces.

Let us consider a WLAN scenario with one AP and two station where STA_1 and STA_2 are modeled after the interface A and B from Table I, for three different WLAN cards. We denote with CW_1 (CW_2) the CW_{min} configuration used by STA_1 (STA_2), and use two different strategies to configure these parameters:

- Strategy *Throughput*: We set $CW_1 = CW_2$, in order to have a fair share of the wireless resources, and perform a sweep on the CW parameter space to choose the value that maximizes throughput.
- Strategy *Efficiency*: We let CW_1 and CW_2 diverge, and we perform a sweep on the CW parameter space to find the configuration that maximizes the energy efficiency η of the WLAN.

We show the results of the throughput per station achieved and the total energy efficiency in Fig. 2, with the following results:

- The first strategy, as expected, provides a bandwidth-fair allocation where both stations receive the same throughput.
- The second strategy, on the other hand, results in an energy-efficiency improvement of approximately 10%. However, the resulting throughput allocation is extremely unfair, as STA_2 is practically starved.

Therefore, the use of *overall* energy efficiency figures is not well suited to properly address realistic (i.e., heterogeneous) scenarios, as it may result in configurations with extreme unfairness across stations. The use of throughput-based approaches, on the other hand, do not consider the impact of the different power consumption parameters and therefore may result in energy wastage. *We argue that a trade-off between these two approaches is needed.*

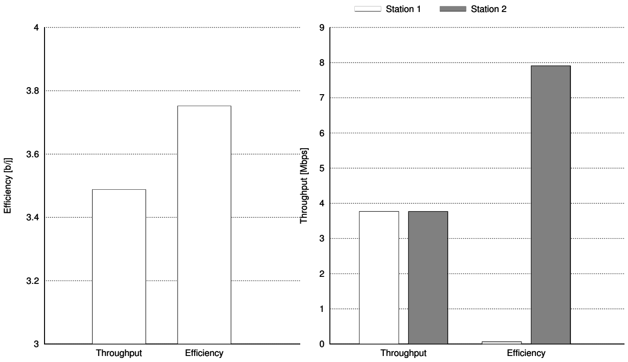

Figure 2. Throughput and Energy-Efficiency performance of a WLAN with two stations modeled after interfaces A (grey) and B (black) from Table I.

We consider Kelly's [3] *proportional fairness* (PF) criterion that defines the proper trade-off to configure the throughput allocation vector r_i as the one that maximizes the sum of the rates' logarithms. In this work we advocate for the use of the energy-efficiency proportional fairness criterion (hereafter the EF criterion), based on the maximization of the sum of the per-station energy efficiency (η_i), i.e.,

$$EF \Longleftrightarrow \max \sum \log \eta_i$$

Note that, with the above definition, in a two station scenario the efficiency of one station would be decreased by say 10% only as long as this allowed an increase in the efficiency of the other station of more than 10%, which represents a balance between two extreme allocations (i.e., throughput is equally shared, or throughput is given to the most efficient station). Our work in [2] devises a close-form expression that calculates the optimal transmission probability that meets the EF criterion.

IV. EXPERIMENTAL EVALUATION

Current manufacturers of wireless chipsets provide basic power information regarding their interface cards. However, it is unclear the accuracy of this information.

In order to analyze and understand the energy consumption of WLAN devices we will propose an experimental methodology in order to meet two contributions: Assess the performance of our previous work in a real testbed, and provide a tool to characterize the power properties of an interface by using off-the-shelf equipment.

Our ongoing experiments are based on a simple testbed: Testing node, power analyzer[1], and a monitor node. The purpose of this scenario is collecting information about the total energy consumed in the proposed set of experiments and sniffing all the traffic generated at the same time. This way we are able to measure the time the testing node spends in transmission, reception and idle state, and the energy consumed.

This information can be used to understand the real behavior of the energy consumption, that is, we can assess the accuracy of our model and eventually, infer the power parameters of wireless cards.

REFERENCES

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[2] A. Garcia-Saavedra, P. Serrano, A. Banchs, and M. Hollick, "Energy-efficient fair channel access for ieee 802.11 wlans," in *World of Wireless Mobile and Multimedia Networks (WoWMoM), 2011 IEEE International Symposium*, June 2011.

[3] F. Kelly, A. Maulloo, and D. Tan, "Rate control in communication networks: shadow prices, proportional fairness and stability," in *Journal of the Operational Research Society*, vol. 49, 1998.

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[1] PCE-PA 6000 power analyzer