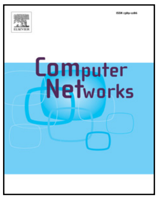
Computer Networks 94 (2016) 99–111

Contents lists available at ScienceDirect

Computer Networks

journal homepage: www.elsevier.com/locate/comnet



The impact of the access point power model on the energy-efficient management of infrastructured wireless LANs

Rosario G. Garroppo, Gianfranco Nencioni, Gregorio Procissi, Luca Tavanti*

Dipartimento di Ingegneria dell'Informazione, Università di Pisa, Italy

ARTICLE INFO

Article history:
Received 11 February 2015
Revised 4 November 2015
Accepted 13 November 2015
Available online 28 November 2015

Keywords:
Wireless LAN
Optimisation
Power consumption model
Energy efficiency
Network management
Resource allocation

ABSTRACT

The reduction of the energy footprint of large and mid-sized IEEE 802.11 access networks is gaining momentum. When operating at the network management level, the availability of an accurate power model of the APs becomes of paramount importance, because different detail levels have a non-negligible impact on the performance of the optimisation algorithms. The literature is plentiful of AP power models, and choosing the right one is not an easy task. In this paper we report the outcome of a thorough study on the impact that various inflections of the AP power model have when minimising the energy consumption of the infrastructure side of an enterprise wireless LAN. Our study, performed on several network scenarios and for various device energy profiles, reveals that simple one- and two-component models can provide excellent results in practically all cases. Conversely, employing accurate and detailed power models rarely offers substantial advantages in terms of power reduction, but, on the other hand, makes the solving algorithms much slower to execute.

1. Introduction

The energy saving issue in wireless networks is currently the focus of many research activities. For example, there is a plethora of works dealing with the analysis and reduction of the power consumption in cellular networks [1–3], wireless sensor networks [4,5], wireless mesh networks [6–8], and also wireless Local Area Networks (WLANs) [9–11].

With specific focus on IEEE 802.11-based networks, there is an increasing interest in the design of efficient reconfiguration algorithms to reduce the power consumption of the infrastructure-side when the load is scarce [9,12,13]. Indeed, by turning some access points (APs) off and adjusting the power radiated by the active APs, it is possible to achieve considerable energy savings with respect to the currently widespread technique of continuously operating the WLAN at full power. Obviously, this energy gain shall not be obtained at the expenses of the coverage nor the quality of service levels provided when the transmission power of all APs is set to the maximum.

In designing such reconfiguration algorithms it is often necessary to first define a power model of the AP. On the basis of this model it is then possible to study and perform the optimisation of the system from an energy-aware perspective.

The assumptions on the AP power model have, in general, a non-negligible impact on the output of the energy-management algorithm, especially because the optimisation is often tailored on the features of the model itself. If an inappropriate power model is employed, it might occur that the planned or expected energy improvement is reduced or even nullified. Consequently, the choice of an appropriate power model is crucial for the valid outcome of any reconfiguration algorithm. However, given the plethora of models proposed over the years, it is not easy to understand which is the most suitable.

In this paper, we specifically address the last point, i.e. our goal is providing some insights and indications to help

---

* Corresponding author. Tel.: +39 0502217621.
E-mail address: luca.tavanti@iet.unipi.it (L. Tavanti).

http://dx.doi.org/10.1016/j.comnet.2015.11.018
1389-1286/

choosing the appropriate AP power model for some common and future network scenarios. To this aim, we perform a study on the effectiveness and implications that various AP power models have in minimising the energy consumption of an enterprise WLAN system. We first define a general model of the WLAN and of the AP power consumption. We then build a mathematical programming model to minimise the total power consumption (while guaranteeing that the whole traffic demand is met). Finally we solve it to optimality for various "realisations" of the AP power model, under different network compositions and device energy profiles. At the end of this process, we are able to extract valuable information on the usefulness and impact of the AP power model details.

Going in more detail, we basically build our AP power model on the one defined by Garcia-Saavedra et al. [14], which can be regarded as the most detailed and reliable appeared so far in the literature. In our model, four major elements contribute to the power consumption of the AP: baseline (due to circuitry powering), the radio frontend, the airtime, and the traffic processing cost (power drain of CPU and memory). Then, by selectively excluding one or more of these elements, we obtain less complete models down to the simplest on/off one.

Then, we characterise all the features of the WLAN system in their most general form, without performing rough approximations or simplifications. Indeed, while such approximations and/or simplifications might, on the one hand, lead to a simpler mathematical programming model, on the other hand they might undermine the effectiveness of our study, e.g. by leading to solutions that are not applicable or unsatisfactory for the original problem.

To achieve the maximum energy-saving of the system, we operate through a mathematical program on two decision aspects at the network management level: (i) associating each user terminal to one of the available APs, and (ii) setting the transmission power level of each AP.

The mathematical program we devised is linear (notwithstanding the non-linearity of some functions, as it will be detailed in Sections 3.2 and 4.2) and optimised for fast solving times, so that we can analyse non-trivial network scenarios in acceptable times. The program is solved to optimality by means of a general-purpose Mixed-Integer Linear Programming (MILP) solver, for a wide range of network scenarios and for four different classes of devices. In fact, current (and future) AP equipment is characterised by different ratios among the power drained by its major elements. Consequently, the application of the power model(s) to diverse device classes might lead to different optimisation strategies and resource allocations.

In particular, we distinguish the cases of homogeneous and heterogeneous networks. While the former is undoubtedly the most utilised in the literature, and also quite common in practice (e.g. brand new deployments), it is becoming not so infrequent for large WLANs to be composed of different types of APs (e.g. due to replacement of malfunctioning equipment, upgrades of old apparatuses, network densification after the initial deployment). Indeed, our work unveils interesting findings about heterogeneous networks which have often been neglected in the literature under the reasoning that passing from a homogeneous to a heterogeneous network is just a matter of more complex notation.

1.1. Contribution

The main contribution of the paper can be summarised as follows.

- We provide an extensive analysis of the impact that the various elements of the AP power model have in optimising the energy efficiency of an enterprise-grade WLAN. This is achieved by means of a general integer linear program of the WLAN which accounts for an accurate and modular power model of the AP and for non-simplistic network features.
- On the basis of the analysis, we delineate the best strategy to minimise the energy consumption in current and future WLANs. We show that accounting for traffic processing at the APs is detrimental, because it hardly brings any improvements in terms of energy savings but makes the problem much harder to execute. We also demonstrate that resource consolidation is often the best strategy. We find that the presence of heterogeneous devices might be exploited to increase the energy efficiency of the system.

The rest of the paper is structured as follows. In the next section we give a brief summary of the related literature and works. Then, in Section 3 we illustrate the analytical model of the WLAN system, with particular emphasis on the power model of the AP, and sketch the mathematical formulation of the problem. Section 4 describes the framework under which we lead our analysis, whose results are reported and commented in Section 5. Finally, the concluding remarks are drawn in Section 6.

2. Related work

Over the years, several AP power models have been proposed, with diverse assumptions and varying degrees of detail. For example, simple on/off models, in which the AP has a constant power drain, have been and are still widely used. A more sophisticated and yet quite popular model ascribes the energy consumption to two elements: a baseline one, plus a term that depends – often linearly – from the activity of the radio interface, the so-called airtime [15]. Then, various measurement campaigns have led to characterise the power consumption as a (variably complex) function of the traffic load, antenna settings (especially for MIMO devices), datagram size, transmission/reception data rate, encryption, number of connected clients [16–19].

Recently, a very detailed AP power model has been described by Garcia-Saavedra et al. in [14]. The model is extracted from a series of accurate measurements on various real APs. It comprises, in addition to the "classic" baseline and airtime elements, a factor that weights the energy cost of processing the traffic.

In parallel to AP power modelling works, several studies have been produced on the optimisation of the WLAN power consumption. Each of these have assumed the APs to be characterised by a specific power model. For example, Jardosh et al. [20] proposed a strategy to dynamically turn APs on/off to follow the resource demand of the users. This approach, which has been translated into a working testbed, was based on empirical considerations, including the simple on/off AP power model.