



Energy-performance trade-off in dense WLANs: A queuing study

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ABSTRACT

The increasing concern about the energy consumption of communication networks is driving the research community to identify approaches to save energy in the networks of today. For instance, considering wireless local area networks (WLANs), the activation of network resources can be driven by the user demand, avoiding having to always power on all Access Points (APs). In this paper, we consider a portion of a dense WLAN system, where many APs are deployed to provide sufficient capacity to serve a large number of active users during peak traffic hours. To provide large capacity, a number of APs are collocated in the same position and provide identical coverage; we say that these APs belong to the same *group*, and they serve users in the same area. The areas covered by different groups only partially overlap, so that some active users can only be served by a group of APs, but a fraction of active users can be served by several groups. Due to daily variations of the number of active users accessing the WLAN, some APs can be switched off to save energy when not all the capacity is needed. The main focus of our study is the investigation of the type of algorithm that should be used for the association of active users with APs in order to increase the amount of saved energy in dense WLANs. Results show that when some system state information is available, such as the number of users associated with each AP, the energy consumption can decrease up to 20%. Furthermore, our study gives comprehensive insights on the trade-off between the opposite needs to save energy and provide quality of service to the users.

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1. Introduction

Dense, centrally managed wireless local area networks (WLANs), where a very large number of Access Points (APs) is installed to provide users with a bandwidth comparable to that of wired Internet access, are becoming common in large enterprises (some industrial campuses report over 10,000 APs). Dense WLANs can also be identified in academic campus networks, although density is usually lower in this case. As an example, consider that at the time of writing this paper, in the office of one of the authors at Politecnico di Torino, the signals of 20 APs were received

by the inSSIDer Wi-Fi scanner [1], 14 of which belonging to the institutional campus network. In these cases, the WLAN deployment is often designed making use of *clusters* of APs that provide coverage and capacity over the same area. Centralized management of the clusters provides a powerful instrument for the implementation of schemes that handle interference, trying to minimize its effect while optimizing coverage and performance. For example, when traffic is low and relatively little capacity is needed, these management algorithms might decide to switch off some channels, i.e., APs, to reduce interference. Recently, the growing awareness of the need to save energy [2], with the twofold objective of reducing cost and being friendly with the environment, has introduced the use of these centralized management schemes as means to improve energy-efficiency in dense WLANs [3]. Thus, these management schemes try to

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find a good trade-off among coverage, energy consumption, performance.

In this paper, we consider a portion of a dense WLAN system, where many APs are deployed to provide sufficient capacity to serve a large number of active users during peak traffic hours. To provide large capacity, a number of APs are colocated in the same position and provide identical coverage; we say that these APs belong to the same *group* and they serve users in the same area. The areas covered by different groups only partially overlap, so that some active users can only be served by a group of APs, but a fraction of active users can be served by more than one group. Due to daily variations of the number of active users accessing the WLAN, some APs can be switched off to save energy when not all the capacity is needed. The main focus of our study is the investigation of the type of algorithm that should be used for the association of active users with APs in order to increase the amount of saved energy in dense WLANs.

Previous simulation and experimental studies in this context considered real but small WLAN setups [3], while analytical studies considered a portion of the WLAN area in which several APs exist, all providing *exactly* the same coverage [4]. In this paper, we extend the analysis of [4] to a portion of the WLAN where two groups of APs offer service over a given service area, that is the union of the two areas resulting from the coverage of the two groups. This is quite a significant extension with respect to [4], since in the case of [4] the choice of the AP to which an active user should connect is trivial. On the contrary, in the new setting, the algorithm that the active users in the area covered by both groups of APs adopt for the selection of the AP to which they should connect, influences the energy consumption of the WLAN.

To investigate the energy-performance trade-off, we develop a model based on two coupled queues: each queue represents a group of colocated APs, and customers arriving at the system might be served by one or both queues depending on their position, that is probabilistically represented in the model. We also propose extensions of the model to the case of more than two groups of APs. Due to the growth of the state space with the number of groups, the extensions are based on accurate approximations that we discuss in the final part of this paper.

Queueing models have been for many years one of the most popular tools for the quantitative analysis and design of computer and telecommunication systems, from telephony to packet networks. The types of metrics traditionally derived from queueing models are extremely varied, ranging from very simple indicators, like the average number of waiting customers, or the average time in the queue, to more elaborate parameters, like, for example, server busy and idle period duration distributions. Of course, the metrics of interest depend on the type of system and on the objective of the quantitative analysis.

Very little interest was paid in the past to metrics related to the system energy consumption. This is not due to a limitation in the modeling power of queues; rather, it reflects the lack of attention that in the past was paid to the energy characteristics of computer and telecommunication systems. Now, energy consumption has become

an important element of the design space, and models are being developed with the objective of characterizing the energy properties of ICT systems of different types. As a result, energy-related metrics have started to appear in the context of queueing models. Examples of recent papers where queues are used to assess the energy properties of systems are [5], where an M/GI/1 queue with processor sharing service is used to investigate the energy properties of dynamic speed scaling in processor sharing systems, and [6,7], where single-server and multi-server queueing models of server farms are investigated, with the objective of identifying server management algorithms that optimize the Energy-Response time product.

In the context of green networking, solutions based on the use of sleep modes have been proposed in many different scenarios and contexts as approaches that, while being effective, are also easily applicable to already available technologies. Many papers consider the case of cellular access networks. In [8], the authors show that, in urban areas, it is possible to put some base stations in sleep mode during low-traffic periods, while still guaranteeing quality of service (QoS) constraints in terms of blocking probability and electromagnetic exposure limits. The impact on the power consumption of deployment strategies based on layouts featuring varying numbers of micro base stations per cell in addition to conventional macro sites has been investigated in [9]. For scenarios with full traffic load, the use of micro base stations has a rather moderate effect on the area power consumption of a cellular network. In [10], the authors evaluate the energy saving that can be achieved with the energy-aware cooperative management of the cellular access networks of more than one operator offering service over the same area. In [11], the authors propose a component-level deceleration technique in base stations operation, called Speed-Scaling, that is more conservative than entirely shutting down BSs; it dynamically saves power during periods of low load while ensuring full coverage at all times. The proposed distributed iterative algorithm, SpeedBalance, addresses the tradeoff between delay and energy in both networking and processing components of BSs. Extensive simulations show that SpeedBalance can yield to significant energy savings of about 30–45%. In [12], the authors show how cooperation increases the covered area of a base station. They propose a model to compute the power needed to cover an area and analyze how cooperation reduces the power consumption. Based on the performed analysis, they also show that using a small number of base stations to cooperate on the transmission to mobile devices is sufficient to save significant amounts of power.

This paper is organized as follows: Section 2 contains the problem statement, with the description of the considered portion of the dense WLAN, and its queueing model, together with the definition of performance metrics and customer management algorithms. Section 3 presents and discusses numerical results obtained with the detailed model of the system. Section 4 describes the approximate models and discusses their accuracy, as well as their use in more general settings. Finally, Section 5 concludes the paper.

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