Computer Networks 56 (2012) 2506–2521

Contents lists available at SciVerse ScienceDirect

Computer Networks

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

Measurement-based modelling of power consumption at wireless access network gateways ☆

Karina Gomez [a,b], Dejene Boru [b], Roberto Riggio [a,*], Tinku Rasheed [a], Daniele Miorandi [a], Fabrizio Granelli [b]

[a] CREATE-NET, Via Alla Cascata 56/C, 38123 Trento, Italy
[b] DISI – University of Trento, Via Sommarive 14, 38100 Trento, Italy

ARTICLE INFO

Article history:
Received 30 September 2011
Received in revised form 23 February 2012
Accepted 20 March 2012
Available online 19 April 2012

Keywords:
Green Networking
WiMAX
WiFi
Power consumption
Energy efficiency
Modelling

ABSTRACT

Improving the energy efficiency of the ICT sector is becoming an ambitious challenge for industries and research communities alike. Understanding how the energy is consumed in each part of an ICT system becomes fundamental in order to minimize the overall energy consumed by the system itself. In this paper, we propose an experimentally-driven approach to (i) characterize typical wireless access network gateways from an energy consumption standpoint and (ii) develop simple and accurate power consumption models for such gateways. In this work we focused our attention on the monitoring, measurement and analysis of the energy consumption patterns of WiFi and WiMAX gateways. Our measurements show that the power consumption of such gateways exhibits a linear dependence on the traffic until a saturation point is reached.

1. Introduction

In the last decade, "Green Networking" [2–5] has gained considerable importance for both commercial entities and researchers that aim at understanding and reducing the energy consumption of computing and communication infrastructures [6,7]. Several studies have shown that the ICT sector accounts for 2–7% of the global energy consumption [8,9,3] and it is also responsible for 2–3% of total emissions of CO_2 [10–12]. Moreover, it is important to remark that about 50% of the total energy used in the ICT sector is consumed at the wireless access part [10,12]. Therefore, network operators and service providers currently compete to optimize the energy efficiency of their access infrastructure in order to reduce both CO_2 emissions and operational costs [13].

In such a scenario, two broadband wireless access technologies, WiFi and WiMAX, are witnessing an increasing usage in both metropolitan and rural deployments. The reason behind their adoption lies in the minimal supporting infrastructure required for their operations, which in time enables a high level of flexibility in network deployments, allowing connectivity to be provided only where *and* when needed. Such fluidity in network deployment and operations is made possible by the architectural choices underpinning the standards. However, while energy efficiency trade-offs have been taken into account for the end-users' terminal, which can be mobile or nomadic, less attention has been devoted to the network gateways which, in either the WiFi and the WiMAX standards, are typically connected to the power grid and, thus,

☆ Part of the results appeared in Proc. of IEEE GreenCom [1]. The research leading to these results are supported partially by the European Community's Seventh Framework Programme (FP7/2007-2013) within the framework of the SMART-Net Project (Grant No. 223937).

* Corresponding author.
E-mail addresses: karina.gomez@create-net.org (K. Gomez), dejene-boru.oljira.1@studenti.unitn.it (D. Boru), roberto.riggio@create-net.org (R. Riggio), tinku.rasheed@create-net.org (T. Rasheed), daniele.miorandi@create-net.org (D. Miorandi), granelli@disi.unitn.it (F. Granelli).

1389-1286/$ - see front matter © 2012 Elsevier B.V. All rights reserved.
http://dx.doi.org/10.1016/j.comnet.2012.03.028

do not pose energy consumption challenges. As a result there is a lack of best practices for designing energy efficient network protocols and architectures for broadband wireless access networks.

The main objective of this work is to experimentally measure and analyse the energy consumption patterns of WiFi and WiMAX gateways[1] at both the component and the network level. In particular, our experiments aim at answering the following questions:

- Where and how is the power consumed in WiFi and WiMAX access gateways? How much of the power is wasted?
- What is the relationship between traffic load and power consumption in WiFi and WiMAX access gateways?
- What are the critical aspects of the IEEE 802.11 and the IEEE 802.16 standards with respect to power consumption?

It is the authors' standpoint that the answers to these questions are very important since they would provide us with an increased insight into the network behaviour, paving the way to the development of (i) realistic models for power consumption in wireless networks and (ii) protocols and algorithms for their operations. The main contributions of the paper are the following:

- An empirical approach for understanding the energy consumption behaviour of WiMAX and WiFi gateways. Thereby, we target the characterization of the power consumption of WiFi and WiMAX gateways in terms of (i) the amount of traffic sent/received by the node, (ii) the modulation and coding schemes used, and (iii) the size of the session level data units.
- A simple model for the characterization of the power consumption in WiFi and WiMAX access gateways is presented.

The remainder of this paper is organized as follows. In Section 2 we present the experimental settings and methodology used. Experimental results are reported and discussed in Section 3. In Section 4 we discuss energy efficiency metrics and models. A brief analysis of the related works on measurement driven energy efficiency analysis is presented in Section 5. Finally, Section 6 is devoted to the final conclusions and pointers to promising research directions.

2. Evaluation methodology

In this section, we will describe the network setups and the methodology used in order to evaluate the power efficiency of the two wireless networking technologies that have been considered in this paper, namely an indoor WiFi network deployed in a typical office environment and an outdoor WiMAX network deployed in a rural area. The network setups exploited in the WiMAX and the WiFi scenarios are sketched respectively in Fig. 1a and b.

2.1. Network settings

In the WiMAX case, the network is composed of a Base Station deployed on the rooftop of a building and a single static Subscriber Station (SS) deployed on the rooftop of another building. The testbed is deployed across the Orange Labs Campus in Lannion, France. The BS and the SS are about 800 m away from each other and are operating under line of sight conditions. The WiMAX equipment is compliant with the IEEE 802.16-2004 version of the standard and implements the TDD duplexing scheme. The devices operate between 5.47 and 5.725 GHz using omni–directional antennas with a gain of 8 dB. With regard to QoS, the devices support the Best Effort (BS), the Real-time Polling Service (rtPS), the Non-real-time Polling Service (nrtPS), and the Unsolicited Grant Service (UGS) traffic classes. The BE class has been used throughout the entire measurements campaign reported in this work.

In the WiFi case, the network is composed of a custom IEEE 802.11g Access Point and a single DELL Latitude D620 notebook acting as static wireless client. The testbed is deployed at CREATE-NET premises in Trento, Italy. The AP is built around a PCEngines ALIX 2C2 (500 MHz $\times$86 CPU, 256 MB of RAM) processor board equipped with two IEEE 802.11a/b/g wireless interfaces (Atheros AR5213A chipset) with RTC/CTS disabled, while the notebook is equipped with an Intel PRO/Wireless 3945AB wireless adapter. The frequency of operation of the AP is 2.412 GHz and the antenna is omni-directional with a gain of 8 dB.

It is important to note that, unless otherwise specified, the rate adaptation algorithm has been set to *auto* and the transmission power has been left to its default value equal to 18 dBm ($\sim$63.1 mW) for the WiFi and the WiMAX cases.

2.2. Traffic generation and power consumption monitoring

Traffic is generated using the Iperf traffic generator[2] and is injected into the network trough either the *Server* or the *Client*. In the former case, we aimed at measuring the power consumed by the BS/AP when it is acting as transmitter, while in the latter case we aimed at measuring the power consumed by the BS/AP when it is acting as receiver. In both cases the power consumption figures reported in this work refer to the BS/AP.

The power consumption is measured using the *Watts Up?*[3] power meter. *Watts Up?* is a "plug load" meter that measures the amount of electricity used by whatever electrical appliance is plugged into it. The meter incorporates digital electronics to perform accurate power consumption measurements. Such measurements are then logged into the device's internal memory with a granularity of 0.1 Watts and a sampling period of 1 s.

The *Watts Up?* meter is interconnected through its USB interface to the *Server* where a custom data logging software is used in order to extract the power consumption

[1] With a slight abuse of terminology we use the term *gateway* to refer to both the WiMAX Base Station (BS) and to the WiFi Access Point (AP).

[2] Available at: http://iperf.sourceforge.net/.

[3] Available at: http://www.wattsupmeters.com/.