TKN Telecommunication Networks Group

Technische Universität Berlin
Telecommunication Networks Group

Power consumption of WLAN network elements

Salvatore Chiaravalloti, Filip Idzikowski, Łukasz Budzisz
salvatore.chiaravalloti@poste.it
{filip.idzikowski|lukasz.budzisz}@tu-berlin.de

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Abstract

Power consumption data of Access Points (APs) and Network Interface Cards (NICs) in Wireless Local Area Network (WLAN) is presented in this report. Publicly available product data sheets, research articles, technical reports, white papers and user manuals were surveyed for this purpose. Provided database shall be a useful reference for the research community to parametrize studies of power consumption of WLANs.

Contents

List of Acronyms

AP Access Point

CPU Central Processing Unit

DCF Distributed Coordination Function

DSSS Direct-Sequence Spread Spectrum

FHSS Frequency-Hopping Spread Spectrum

FTP File Transfer Protocol

IEEE Institute of Electrical and Electronics Engineers

LAN Local Area Network

MAC Medium Access Control

MIMO Multiple-Input/Multiple-Output

NIC Network Interface Card

OFDM Orthogonal Frequency Division Multiplexing

PA Power Amplifier

PC Personal Computer

PCI Peripheral Component Interconnect

PCMCIA Personal Computer Memory Card International Association

PD Powered Device

PDA Personal Digital Assistant

PoE Power over Ethernet

PSE Power Sourcing Equipment

RF Radio Frequency

RMS Root Mean Square

TCP Transmission Control Protocol

USB Universal Serial Bus

WLAN Wireless Local Area Network

WMM Wi-Fi Multimedia

1 Introduction

Wireless communication has been widely deployed in the last two decades, changing the way people access the Internet. This however raised several concerns, including that of power consumption. Quite some effort has already been undertaken to address this issue, striving for low-energy wireless communication systems. The drivers are manifold and include environmental considerations, as well as cost-efficiency in the energy production and devices' battery lifetime, with the last aspect being the most investigated so far. It is actually worthwhile to consider the other factors too, taking into account that the average power consumption of the network equipment is estimated to be 25 GW during operation worldwide (yearly average in 2008) [1] and a single corporate Wireless Local Area Network (WLAN) may feature more than 5000 Access Points (APs) [2].

The main goal of this work is to provide a database of power consumption of WLAN network elements, such as Network Interface Cards (NICs) and APs. The data presented in this report has been collected from many different sources, including product data sheets, research articles, technical reports, white papers and user manuals. In an attempt to identify trends in the power consumption, the NICs and APs are classified according to the following aspects: the 802.11 standard, the operational mode, and the year the device was produced. Last but not least, this report aims at capturing how the WLAN elements are evolving in the direction of the energy-saving technology at the same time providing a useful database (with direct links to pdf documents) for further power consumption studies.

2 Related Work

Before presenting the collection of NIC and AP power consumption data (Section 3), a brief overview of the related work is given. Analyzed material is grouped according to the publication type.

Research papers Wireless NICs are most often utilized in battery-powered devices such as laptops. Limited capacity of the batteries motivated the work on energy-efficient NICs leaving APs aside despite the fact that APs offer higher potential of power savings, due to their constant operation and higher power consumption than NICs.

The first results on power consumption of NICs were presented in [3]. The authors measured power consumption of a Metricom Ricochet Wireless Modem, an AT&T WaveLAN NIC (at 915 MHz and 2.4 MHz) and an IBM Infrared WLAN adapter. The outcome was used to formulate two power saving strategies (transport-level and application-level) in the form of an explicitly controlled on/off switching of the NIC.

Measurements reported in [4] by Feeney and Nilson provide detailed power consumption data in an ad-hoc network for two WLAN NICs (Lucent WaveLan 802.11 Personal Computer Memory Card International Association (PCMCIA) "Silver" and "Bronze") in different operational modes (Sleep, Idle, Receive and Transmit) and for 2 and 11 Mbit/s data rates.

The instantaneous power consumption of an Aironet PC4800B PCMCIA NIC in three different operational modes was measured in several campaigns [5, 6, 7, 8] varying Radio Frequency (RF) transmission power, data rate and packet size. In [5], the optimum energy saving transmission power level was derived for a given network configuration, channel characteristics and packet length. Based on this result, a power control mechanism dependent on packet length was proposed. The authors performed discrete event simulations of an Institute of Electrical and Electronics Engineers (IEEE) 802.11 Local Area Network (LAN) in an ad-hoc mode using a two state Markov channel model. The achieved simulation results indicate a significant potential for power saving. Further [6, 7, 8] extend the scope of the initial results.

Carvalho et al. [9] presented an efficient energy-aware protocol. The authors introduce an analytical model to predict power consumption in saturated single-hop ad-hoc networks, under ideal channel conditions. The proposed model takes into account different operational modes of the IEEE 802.11 Distributed Coordination Function (DCF) Medium Access Control (MAC). The authors validate this model with discrete-event simulations using Qualnet v3.6. They find out that although the power consumed by a NIC when transmitting data is higher than in any other modes (idle, overhear, sense and receiving), its impact on overall power consumption is practically insignificant as far as the MAC operation in saturation conditions is concerned.

Power consumption of various wireless NICs was indirectly examined in the Atheros white paper [10]. Several laptops with WLAN NICs (spanning major versions of the 802.11 standard) in various modes were used for measurements. The results show that the power consumption of a WLAN NIC depends not only on the operational mode of the WLAN card itself, but also on many additional activities of Central Processing Unit (CPU) and other parts of the laptop (platform) required to operate the WLAN interface.

Impact of rapidly growing segment of portable computing devices on global power consumption was also studied in [11]. The authors characterized power consumption of portable devices like laptops and mobile phones, and estimated their share in the global power consumption. In particular, power consumption of nine laptops in three different conditions (idle with the NIC off, idle with the NIC on (but in the idle mode), and receiving streaming video through the NIC) was measured and reported as a part of this study.

So far, much less work has been done to assess power consumption of APs. Jardosh et al. [12] provide a detailed discussion of the problem of energy wastage in large-scale WLANs, due to the hundreds of idle APs world-wide. The authors point out that networks are rarely used at their peak capacity, and the majority of their resources are frequently idle. Moreover, they also describe resource management strategies for power conservation in WLAN, like resource-on-demand strategy called SEAR (Survey, Evaluate, Adapt, and Repeat). The authors report power measurements of four different APs together with the boot times of these devices. A typical AP is estimated to consume up to 10 W.

Power consumption of three anonymous APs was measured in [13], and broken down into power consumption of radio and base components. Throughput and various forms of encryption/security were taken into account in this study.

Similarly, power consumption of three different APs (Aruba AP 125 [14], Cisco AP1250 [15] and Meru AP320 [16]) in three different operating modes (idle, ready and active) was investigated in [17]. The study has shown that power consumption well below the 802.11af levels (see last paragraph in Section 3.1) is possible. Other metrics like throughput or airtime fairness were also considered. Moreover, the authors demonstrate that the load-based power saving algorithm that was implemented in Meru AP makes it a more power-efficient device than its competitors.

Product data sheets Power consumption values are usually provided in the respective product data sheets available on manufacturer websites. However, vendors of APs and NICs include different level of detail in their product data sheets.

The data usually reported in NICs product data sheets includes: antenna gain, transmit power, receive sensitivity, maximum receive level, 802.11 standard supported (data rates, frequency range, number of available channels), forms of security, operating voltage and temperature, etc. Power consumption values for NICs are, in general, more detailed than these for APs. Several data sheets specify power consumption as a function of operation mode and data rate (or 802.11 standard), see Tables 2 and 3 for further examples.

Concerning APs, available information usually includes: number of radios, number of antennas, range, supported 802.11 standards (frequency band, number of channels), receive sensitivity in dependence of data rate, available transmit power, security features, operating voltage and temperature, etc. Exceptionally, some data sheets provide also antenna plots (e.g., [14]). Nevertheless, information on power consumption of APs available in product data sheets is often quite limited, and in some cases not available at all (e.g., [18]). Most of the product data sheets report maximum power drawn by the device. The typical power consumption is reported less frequently (e.g., [19]).

Summarizing, results of several measurement studies of power consumption of NICs and APs can be found in the literature. However, no comprehensive database of power consumption values of both NICs and APs has been found. As power consumption is becoming a more and more important issue nowadays, we believe that the database presented in the following section will be a useful reference for the research community to parametrize studies of power consumption of WLAN networks.

3 Power consumption in WLAN networks

3.1 Basic terms

In order, to improve the readability of this report, a short summary of the most important topics related to the IEEE 802.11 networks and power management used in this report is first presented. Readers already familiar with the 802.11 standards may well skip this subsection.

IEEE 802.11 standard The IEEE 802 specifications define the family of standards for LANs that deal with the two lowest layers of the ISO Open System Interconnection Reference Model, namely physical and data-link layer. Consequently, the 802.11 standard includes the definition of the 802.11 MAC and various physical layers. The initial version of the standard, called also release 1999, included following physical layers: infrared, Frequency-Hopping Spread Spectrum (FHSS) (both now completely abandoned) and Direct-Sequence Spread Spectrum (DSSS). Later revisions added additional physical layers. The 802.11b extension defined high rate DSSS with data rates up to 11 Mbps in the 2.4 GHz band. Devices compliant to that standard started to appear already in 1999, and thanks to their enormous popularity form an important part of the evaluation presented in this report. Shortly after, the 802.11a extension was released, that defines a physical layer based on Orthogonal Frequency Division Multiplexing (OFDM) with data rates up to 54 Mbps in the 5 GHz band. OFDM was also brought to the 2.4 GHz band with the 802.11g standard, published in 2003. More recently, further improvements to the physical layer were proposed with the 802.11n standard that incorporates Multiple-Input/Multiple-Output (MIMO) enhancements in both 2.4 and 5 GHz band. More details on the evolution of the IEEE 802.11 standard can be found in [20].

Multiple-Input/Multiple-Output MIMO is a method of transmitting multiple data beams on multiple transmitters to multiple receivers. Multiple antennas can be used either at the transmitter or receiver or at both. Such systems are designed to provide high channel capacities in a limited bandwidth, which enables the efficient use of the spectrum. The advantage is that the odds of receiving the data in a lossy wireless channel are massively increased.

Network components According to [21], the main components of the IEEE 802.11 network include:

- **Station**, a terminal with access mechanism to the wireless medium and radio contact to the AP. The scope of this survey is on the stations, e.g., laptops, where the access mechanism is provided by the **Network Interface Card (NIC)**. Thus, mobile phones, smartphones, Personal Digital Assistants (PDAs) are excluded from this study.
- **Access Point (AP)**, a device that relays data between stations. In addition, an AP allows stations to connect to the distribution system which connects to the external networks. Most important (but not the only) function of an AP is to translate the 802.11 frames to another type of frame (e.g., Ethernet) to be delivered to the rest of the world. Each AP can serve multiple users within a defined network area.
- **Distribution System**, a logical connection between several APs to extend the coverage area of a wireless network.

Dual-band A dual-band device is a device that supports both frequency bands of the 802.11 wireless standard. Dual-band a/b/g APs handle 802.11a users in the 5 GHz band, while simultaneously supporting 802.11b/g users in the 2.4 GHz band. Dual-band a/b/g/n APs support both bands for 802.11n as well. Such APs enable 802.11a and 802.11n users to transmit at 5 GHz and 802.11b/g and 802.11n users to transmit at 2.4 GHz. Both bands may run simultaneously or only one band at a time.

Network configurations 802.11 networks can be either configured as infrastructure or ad-hoc networks. In the **infrastructure** configuration, stations communicate with other stations through a special kind of node called AP. To send a frame to another station, a station must first send the frame to the AP, and then the AP will forward the frame to the destination. Infrastructure mode has the advantage of centralized control for sending and receiving wireless frames, however, it poses more overhead than the ad-hoc mode. In the **ad-hoc** configuration all communication between stations is done directly without help of the intermediate AP. Typically ad-hoc networks are composed of a small number of nodes set up for specific purpose and for short time.

Power management Power management has been present in the 802.11 specification since its early days, as an important MAC function. Broadly speaking, power saving in 802.11 can be achieved by minimizing the time the transceiver is active, i.e., transmitting (**TX mode**) or receiving data (**RX mode**), and by maximizing the time spent in the power-saving mode, i.e., either **idle** or **sleep mode**. In the active mode, a station is fully powered, thus it can send and receive frames at any time. Establishing a data transmission channel means that one of the two points of the communication will be the transmitter (and/or receiver) and the other will be the receiver (and/or transmitter). In the power-saving mode, station can be in one of the two states, sleep state or an idle state. For most of the time spent in the power-saving mode, a station remains in the sleep mode, consuming very little power. Transition to the idle state is only made for listening to the management frames called beacons at a certain intervals and for receiving frames from the AP. For further details regarding power management the interested readers are referred to related literature, e.g., [22, 23].

Power over Ethernet Some APs support the Power over Ethernet (PoE) standards: 802.3af (PoE) [24] and/or 802.3at (PoE+) [25]. The 802.3af standard specifies how the power should be distributed along with data over Ethernet LAN cables to the networked devices. The standard allows up to 15.4 Watts of power at the Power Sourcing Equipment (PSE), but a Powered Device (PD) can use no more than 12.95 Watts. The 802.3at standard permits up to 30 Watts of power at the PSE, and up to 25.5 Watts for a PD, respectively. The 802.3at is backward compatible with the 802.3af specification.

3.2 Methodology

The following methodology was used to collect and calculate power consumption values reported in this survey:

- Concerning WLAN stations, this survey is limited to the stations equipped with a NIC and reports power consumption of the NIC elements only.
- The scope of the presented survey of power consumption data of WLAN NICs and APs includes product data sheets, research articles, technical reports, white papers and user manuals. In order to ease the evaluation of the collected data, the research papers are marked in gray in the tables with power data presented in this report. The power data measurements described in the research papers are marked in yellow in the tables.
- Whenever possible, the maximum value of the consumed power in each of the operation modes (see paragraph Power management, in Section 3.1) is reported, otherwise an additional explanation about the reported value is given (e.g., "typ." for a typical value of consumed power, etc.).
- Power consumption was calculated out of supply voltage and current values in case it was not explicitly specified in Watts [W].
- The term "production year" used in this report indicates our approximation of the year in which device was manufactured. As this type of data is usually hard to obtain, the date of the publication of the document that reports the power consumption data was used instead. Such an approximation was used consistently over the entire document, and provides insight into evolution of WLAN devices (or generation of the device) in terms of power consumption.

3.3 Network Interface Cards (NICs)

The collected NICs power consumption data is presented in Tables 1 and 2. The data is divided into two separate categories:

- NICs supporting 802.11-1999/802.11b standard only, and
- NICs with multimode (802.11 a/b/g/n) support.

Table 1: Power consumption of NICs in mW (802.11-1999/802.11b standard)

Device (Prod. year)	Power [mW]			
	Sleep	Idle	RX	TX
Cirrus Wireless PCMCIA Controller CS22220 (not specified) [26]	unspecified	unspecified	1336.5 typ. (continuous RX, 3.3VDC)	1897.5 typ. (continuous TX, 3.3VDC)
AT&T Wavelan PCMCIA card 915MHz (1997) [3]	177.3	1318.9	unspecified	unspecified
AT&T Wavelan PCMCIA card 2.4GHz (1997) [3]	143.0	1148.6	unspecified	unspecified
Metricom Ricochet Wireless Modem (1997) [3]	93.5	346.9	unspecified	unspecified
IBM Infrared WLAN card (1997) [3]	unspecified	349.6	unspecified	unspecified
Lucent WaveLan card (1997) [3, 27, 28, 29]	45	1150	1400	1650
Intersil WLAN Personal Computer (PC) Card WLANKITPR1 (1998) [30]	150 typ (5VDC)	unspecified	1435 typ. (5VDC)	2440 typ. (5VDC)
Intersil PRISM II 11Mbps WLAN PCMCIA Card HWB3163 (1999) [31]	56.1 max. (3.3VDC)	unspecified	709.5 (continuous RX, 3.3VDC)	1254 (continuous TX, 3.3VDC)
Intel PRO/Wireless 2011 LAN PC Card WPC2011EU (2000) [32]	33 typ., 82.5 max. (3.3VDC)	unspecified	561 typ., 990 max. (3.3VDC)	990 typ., 1650 max.(3.3VDC)
Intersil PRISM 2.5 11Mbps WLAN PC Card ISL37300P (2001) [33]	unspecified	204.6 typ. (Power Save mode, 3.3VDC)	676.5 typ. (continuous RX, 3.3VDC)	957 typ. (continuous TX, 3.3VDC)
Lucent IEEE 802.11 WaveLAN PC ”Bronze” (2Mbps) (2001) [4]	66.36 (4.7VDC) (avg)	836.6 (4.7VDC) (avg)	958.8 (4.7VDC) (avg)	1316 (4.7VDC) (avg)
Lucent IEEE 802.11 WaveLAN PC ”Silver” (11Mbps) (2001) [4]	47 (4.7VDC) (avg)	733.2 (4.7VDC) (avg)	893 (4.7VDC) (avg)	1334.8 (4.7VDC) (avg)
3Com 11Mbps WLAN PC Card with XJACK Antenna 3CRWE62092A (2001) [34]	105.6 typ. (3.3VDC)	unspecified	1023 typ. (3.3VDC)	1122 typ. (3.3VDC)
Intersil PRISM 2.5 11Mbps WLAN miniPCI Card ISL37400M (2001) [35]	unspecified	207.9 typ. (Power Save mode, 3.3VDC)	660 typ., 742.5 max. (3.3VDC)	1072.5 typ., 1254 max. (3.3VDC)

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Table 1 – continued from previous page

Device (Prod. year)	Power [mW]			
	Sleep	**Idle**	**RX**	**TX**
3Com 11Mbps WLAN Peripheral Component Interconnect (PCI) Adapter 3CRDW696 (2002) [36]	unspecified	unspecified	unspecified	1485 typ. (3.3VDC), 1500 typ. (5VDC)
Cisco Aironet PC4800B Intersil PRISM I PCMCIA interface (2002) [5, 6, 7, 8, 37]	75 (5VDC, data sheet and measurements),	1340 (5VDC, measurements)	1500 (data sheet), ca. 1410 (5VDC, measurements)	2200 (data sheet), ca. 1910 (5VDC, measurements)
Simulated NIC (2004) [9]	unspecified	unspecified	1400	1650
Lucent WaveLAN (1Mbps) (2004) [9]	unspecified	unspecified	1400	1650
Lucent WaveLAN (11Mbps) (2004) [9]	unspecified	unspecified	900	1400
Intel PRO Wireless 2100 miniPCI Card (2004) [38]	128 (radio disabled)	294 (associated)	1386	1914
Cisco Aironet 350 Wireless LAN PC Client Adapter AIR-PCM35x (2005) [39]	75 typ. (5VDC)	unspecified	1250 typ. (5 VDC)	2250 typ. (5VDC)
Cisco Aironet 350 Wireless LAN LM Client Adapter AIR-LMC35x (2005) [39]	75 typ. (5VDC)	unspecified	1250 typ. (5VDC)	2250 typ. (5VDC)
Cisco Aironet 350 Wireless LAN PCI Card Client Adapter AIR-PCI35x (2005) [39]	575 typ. (5VDC)	unspecified	1750 typ. (5VDC)	2750 typ. (5VDC)
Cisco Aironet 350 Wireless LAN Mini PCI Card Client Adapter AIR-MPI350 (2005) [39]	49.5 typ. (3.3VDC)	unspecified	1089 typ. (3.3VDC)	1881 typ. (3.3VDC)

Power consumption data collected from data sheets, user manuals and research papers often appears to be very heterogeneous and thus difficult to compare. Usually, and that seems to be the biggest drawback of this survey, there is not enough information about how the power consumption measurements were performed (at the manufacturer side), what kind of load conditions were assumed for active mode power consumption, etc. Measurement conditions may also vary – this is the case for most of the data that was collected from the product data sheets.

In order to make such a comparison possible, the scope of the analyzed data has been limited to NICs operating in the same frequency band and supporting the same standard (802.11-1999/802.11b), but even then it is very difficult to draw any definite statements. Fig. 1 presents the reported power consumption of eleven different NICs in sleep, idle, RX and TX mode, accordingly. Power values in the idle mode are unavailable for some cards. First thing to notice is that the power consumption is not decreasing over time, as the new generations of the devices are developed. This is due to the fact that more complex and thus more power consuming subcomponents were used, as the

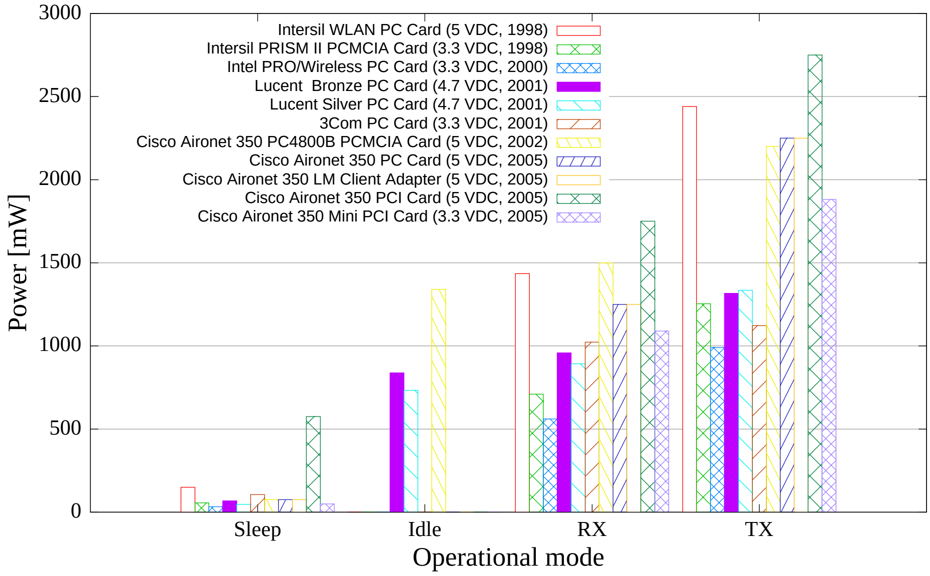

Figure 1: Power consumption of 802.11-1999/802.11b NICs against their operational mode with the indication of applied DC voltage and production year. Power values for eight NICs in idle mode are unavailable.

standard developed. This is compensated by the increased data rates that make the overall time spent on data transmission/reception smaller. Naturally, transmission mode influences power consumption, with more power being used in the TX mode (due to the Power Amplifier (PA) that has to amplify the strength of the output signal). The difference in power consumption between the idle, RX and TX modes is not significant, though. It is the sleep mode that introduces substantial power savings. It is interesting to note, however, that Cisco Aironet 350 PCI Card [39] consumes more power in the sleep mode than the Intel PRO/Wireless PC Card [32] in the RX mode. This is due to the fact that the Cisco NIC is a PCI Card, an interface used in desktops and thus consuming more power than the PCMCIA or Mini-PCI cards used in laptops.

In general, power consumption is proportional to the applied voltage, i.e., the lower the voltage, the lower the power consumption for each operational mode. Lucent NICs powered at 4.7 VDC are an exception from this rule. They consume comparable amount of power to the Cisco Aironet 350 PCI Card and 3Com PC Card (both at 3.3 VDC). The Intel PRO/Wireless card consumes the smallest amount of power among all considered NICs in all operational modes, where data is available (sleep, RX and TX modes).

Table 2: Power consumption of NICs in mW (multimode 802.11 standards)

Device (Prod. year)	802.11 stand.	Power [mW]			
		Sleep	Idle	RX	TX
Mini-PCI VIA Wireless LAN Module WMV-01-R20 (unspecified) [40]	b	unspecified	unspecified	unspecified	825 (3.3VDC) [1]
	g	unspecified	unspecified	unspecified	759 (3.3VDC) [1]
Mini-PCI Realtek Wireless LAN Module WMR-01(unspecified) [40]	b	unspecified	unspecified	unspecified	1122 (3.3VDC)[1]
	g	unspecified	unspecified	unspecified	1089 (3.3VDC)[1]
Mini-PCI Ralink Wireless LAN Module WMRA-01 (unspecified) [40]	a	unspecified	unspecified	unspecified	1283.7 (3.3VDC)[1]
	b	unspecified	unspecified	unspecified	1237.5 (3.3VDC)[1]
	g	unspecified	unspecified	unspecified	1072.5 (3.3VDC)[1]
Universal Serial Bus (USB) embedded module with VIA wireless LAN module WMUSB-V01-R20 (unspecified) [40]	b/g	unspecified	unspecified	1525 (5VDC)	1910 (5VDC)
PCIe mini card wireless LAN module WMPCIE-V01-R20 (unspecified) [40]	b	unspecified	627 (3.3VDC)	924 (continuous RX, 3.3VDC)	1386 (continuous TX, 3.3VDC)
	g	unspecified	627 (3.3VDC)	990 (continuous RX, 3.3VDC)	1221 (continuous TX, 3.3VDC)
Sparklan 802.11n draft Mini-PCI Module WMIR-215GN (unspecified) [41]	b	unspecified	unspecified	1112 (continuous RX, 3.3VDC)	2013 (continuous TX, 3.3VDC)

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[1]The operational mode at which the power consumption was measured is not explicitly specified in the data sheets. TX mode is assumed.

Table 2 – continued from previous page

Device (Prod. year)	802.11 stand.	Power [mW]			
		Sleep	Idle	RX	TX
	g	unspecified	unspecified	1112 (continuous RX, 3.3VDC)	2013 (continuous TX, 3.3VDC)
	HT20	unspecified	unspecified	1112 (continuous RX, 3.3VDC)	2310 (continuous TX, 3.3VDC)
	HT40	unspecified	unspecified	1112 (continuous RX, 3.3VDC)	2376 (continuous TX, 3.3VDC)
Belkin Dual-Band Wireless PCI Network Card F6D3000 (2004) [42]	a/b/g	unspecified	unspecified	825 (3.3VDC)	1848 (3.3VDC)
Belkin Dual-Band Wireless PCMCIA Network Card F6D3010 (2004) [43]	a/b/g	unspecified	unspecified	825 (3.3VDC)	1848 (3.3VDC)
Intel PRO Wireless 2200 miniPCI Card (2004) [27, 28, 38]	b	60 (radio disabled)	80 (associated)	850	1450
Dell Wireless 1350 miniPCI Card (2004) [44]	b/g	20 (radio disabled)	740 (associated)	800	1000
Dell Wireless 1450 miniPCI Card (2004) [44]	a/b/g	20 (radio disabled)	740 (associated)	1200	1000
D-Link AirPlus Wireless G PCI Adapter DWL-G510 (2004) [45]	b	990 (3.3VDC)	unspecified	1155 (3.3VDC)	1914 (3.3VDC)
	g	990 (3.3VDC)	unspecified	1089 (3.3VDC)	1815 (3.3VDC)
D-Link AirPlus Wireless G PCI Adapter DWL-G510 (2004) [46]	b/g	15.4 (3.3VDC)	92.4 (Power save Mode, 3.3VDC)	unspecified	818.4 (3.3VDC)

Continued on next page

Table 2 – continued from previous page

Device (Prod. year)	802.11 stand.	Power [mW]			
		Sleep	Idle	RX	TX
Cisco CB20A Wireless LAN PC-CardBus Client Adapter AIR-CB20A (2005) [39]	a	66 typ. (3.3VDC)	unspecified	1914 typ. (3.3VDC)	1716 typ. (3.3VDC)
D-Link High-Powered Wireless 108G PCI Adapter DWL-G550 (2005) [47]	b/g	99 (3.3VDC)	unspecified	990 (continuous RX, 3.3VDC)	1650 (continuous TX, 3.3VDC)
SocketCom CF (2006) [27, 28]	unspecified	unspecified	66	594	924
Agilent Current Drain Analysis WLAN Network Card Test (2006) [48]	a	70.62 (3.3VDC)	1108.8	1138.5 (3.3VDC)	1188.3 (3.3VDC)
Intel PRO/Wireless 3945ABG (802.11a/b/g) Card (2006) [49]	a/b/g	30	150 (nominal)	1400	1800
Cisco Aironet Wireless CardBus Adapter AIR-CB21AG-E-K9 (2007) [50]	a	40 @ 6-24Mbps; 25 @ 6-24, 36Mbps; 20@ 6-54Mbps; 13@ 6-54Mbps; 10 @6-54Mbps	669.9 @54Mbps 669.9 @18Mbps	1049.4 @54Mbps 1079.1 @18Mbps	1828.2 @54Mbps 1778.7 @18Mbps
	b	unspecified	669.9 @11Mbps	930.6 @11Mbps	1749 @11Mbps
	g	unspecified	669.9 @54Mbps 669.9 @18Mbps	1049.4 @54Mbps 1079.1 @18Mbps	1828.2 @54Mbps 1778 .7 @18Mbps
D-Link Wireleess G USB Adapter DWA-110 (2007) [51]	b/g	unspecified	unspecified	1400 (5VDC)	2300 (5VDC)

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Table 2 – continued from previous page

Device (Prod. year)	802.11 stand.	Power [mW]			
		Sleep	Idle	RX	TX
D-Link Wireless G PCI Adapter DWA-510 (2007) [52]	b/g	49.5 (3.3VDC); 75 (5VDC)	unspecified	858 (3.3VDC); 1300 (5VDC)	1485 (3.3VDC); 2250 (5VDC)
SMC EZ Connect g 802.11g Wireless PCI Adapter[2] (2008) [53]	b/g	unspecified	unspecified	1155 (3.3VDC)	1881 (3.3VDC)
Cisco Linksys Dual-Band WirelessN Express-Card WEC600N[2] (2008) [54, 55]	b/g/n	396 (3.3VDC)	unspecified	1980 (3.3VDC)	2640 (3.3VDC)
Cisco Aironet Wireless PCI Adapter AIR-PI21AG-E-K9 (2010) [56]	a	40 @ 6-24Mbps; 25 @ 6-24, 36Mbps; 20@ 6-54Mbps; 13@ 6-54Mbps; 10 @6-54Mbps	669.9 @54Mbps 669.9 @18Mbps	1049.4 @54Mbps 1079.1 @18Mbps	1828.2 @54Mbps 1778.7 @18Mbps
	b	unspecified	669.9 @11Mbps	930.6 @11Mbps	1749 @11Mbps
	g	unspecified	669.9 @54Mbps 669.9 @18Mbps	1049.4 @54Mbps 1079.1 @18Mbps	1828.2 @54Mbps 1778.7 @18Mbps
IOGEAR Wireless USB Host Adapter GUWA100U (2010) [57]	unspecified	unspecified	unspecified	unspecified	2100 (5VDC from USB port)[1]

Data collected in Table 2 is often incomplete because of the lack of information about the operation modes in product data sheets. Another aspect, important in terms of evaluating collected results, is the verification of the data reported by the device manufacturers. In some cases it was possible to obtain the power consumption data of the same NIC coming from two different sources. This was the case for D-link DWL-G510 NIC, reported in [45, 46] with significantly different values. Meanwhile, various Cisco NICs are reported to consume the same amount of power, e.g., [50, 56].

[2] A voltage supply of 3.3 VDC was assumed

The trend that can be clearly seen among the collected data is that the development of the 802.11 standard, and thus definition of new physical layers, contributes to improvements in terms of power efficiency. While having similar power consumption as in the 802.11b mode, devices operating 802.11a/g offer higher data rates, and will effectively spend less time transmitting or receiving the same amount of data what will result in smaller energy footprint. Within the same standard the differences in power consumption are caused by different architectural, algorithmic and implementation decisions made by a particular manufacturer, and lead to a difference of factor approx. 3 between the least and the most power-consuming NIC (for 802.11g standard).

Another good news in terms of power consumption, is the (time) trend of the power consumption in the sleep mode. Despite the fact that the devices were constantly improved to support newer standards, power consumption in the sleep mode is maintained at the very low level, making considerable power saving with the efficient power management in the WLAN networks still feasible.

A special, separate group of the collected data form the indirect NICs power consumption measurements. Article [10] reports the NICs power consumption measured by comparing device (i.e., a laptop) power consumption with the WLAN NIC powered off and on receiving/transmitting Transmission Control Protocol (TCP) data either in uplink or downlink direction. Somavat et al. [11] report on further results in downlink direction using video streaming as an application. They also report studies performed previously that provide the breakdown of power consumption among various laptop subcomponents. This is however beyond the scope of this report that focuses on the overall power consumption of NICs only. Indirect NIC power measurement data is also reported in [58], where the File Transfer Protocol (FTP) traffic is transferred in uplink and downlink direction. It is interesting to note that all the indirectly measured power values of the Intel Pro Wireless 2100 NIC are higher than the ones in the data sheet [38] (see Table 1). TCP traffic was also used in [59], where power consumption of Soerkis net4521 without and with various NICs in 802.11a and 802.11b standards was measured.

Table 3 summarizes indirect NICs power consumption measurements.

Table 3: Estimation of power consumption of NICs with measurements of power consumption of platforms with NICs on and off

Device (Prod. year)	802.11 stand.	Power [mW]			
		Sleep	Idle	Downlink	Uplink
Cisco Aironet 5 GHz PC Card on Pentium 4 platform (2003) [10]	b	450 (searching)	1590 (Power save off) 1040 (Power save on)	7280 (TCP Downlink)	6960 (TCP Uplink)
Agere PC Card on Pentium 4 platform (2003)[10]	b	420 (searching)	980 (Power save off) 140 (Power save on)	10580 (TCP Downlink)	9370 (TCP Uplink)

Continued on next page

Table 3 – continued from previous page

Device (Prod. year)	802.11 stand.	Power [mW]			
		Sleep	Idle	Downlink	Uplink
Centrino Intel Pro/Wireless 2100 MiniPCI Card on Pentium M platform (2003)[10]	b	780 (searching)	1820 (Power save off) 910 (Power save on)	3500 (TCP Downlink)	3350 (TCP Uplink)
Intersil/Symbol PC Card on Pentium 4 platform (2003)[10]	b	540 (searching)	1950 (Power save off) 460 (Power save on)	8840 (TCP Downlink)	7420 (TCP Uplink)
Intersil PC Card on Pentium 4 platform (2003)[10]	g	1290 (searching)	2020 (Power save off) 1320 (Power save on)	7150 (TCP Downlink)	6010 (TCP Uplink)
Broadcom PC Card on Pentium 4 platform (2003)[10]	g	2630 (searching)	1810 (Power save off) 1780 (Power save on)	7460 (TCP Downlink)	6750 (TCP Uplink)
Atheros AR5001+ CardBus Card (2003)[10]	a	130 (searching)	1970 (Power save off) 750 (Power save on)	7480 (TCP Downlink)	7190 (TCP Uplink)
	b	240 (searching)	2590 (Power save off) 870 (Power save on)	5850 (TCP Downlink)	6150 (TCP Uplink)
	g	330 (searching)	2560 (Power save off) 920 (Power save on)	8450 (TCP Downlink)	8360 (TCP Uplink)

Continued on next page

Table 3 – continued from previous page

Device (Prod. year)	802.11 stand.	Power [mW]			
		Sleep	Idle	Downlink	Uplink
HP pavilion dv4t NIC (2010) [11]	unspecified	unspecified	1000	2000	unspecified
Dell Inspiron 1525 NIC (2010) [11]	unspecified	unspecified	3000	15000	unspecified
Compaq Presario C300 NIC (2010) [11]	unspecified	unspecified	2000	6000	unspecified
Dell Inspiron 1440 NIC (2010) [11]	unspecified	unspecified	1000	6000	unspecified
6 Aspire 4730Z NIC (2010) [11]	unspecified	unspecified	2000	4000	unspecified
Dell Inspiron XPS M1310 NIC (2010) [11]	unspecified	unspecified	3000	12000	unspecified
Hp pavilion dv 2000 NIC (2010) [11]	unspecified	unspecified	7000	8000	unspecified
Fujitsu Siemens AMILO M7440 NIC (2010) [11]	unspecified	unspecified	2000	6000	unspecified
Lenovo ThinkPad X60 NIC (2010) [11]	unspecified	unspecified	4000	7000	unspecified
Intel Pro Wireless 2100 on IBM ThinkPad R40 laptop (2004)[58]	unspecified	unspecified	1000 (Power save off) 140 (Power save on)	2550 (receiving via FTP at 2.9 Mb/s)	3120 (transmitting via FTP at 4.2 Mb/s)
Senao 2511CD plus ext2 using Prism2 chipset, PCMCIA (2006) [59]	b	unspecified	140	560 (TCP Downlink)	1480 (TCP Uplink)
Orinoco Gold, PCMCIA (2006) [59]	b	unspecified	770	910 (TCP Downlink)	1100 (TCP Uplink)
Atheros NL-5354MP+, miniPCI (2006) [59]	b	unspecified	1410	1550 (TCP Downlink)	1930 (TCP Uplink)
	a		1600	1600 (TCP Downlink)	3190 (TCP Uplink)
DLink DWL a650, PCMCIA (2006) [59]	a	unspecified	1320	1320 (TCP Downlink)	1570 (TCP Uplink)

Report [10] is one of the first works trying to compare experimentally power consumption of NICs of various vendors using the same platform. As reported estimates of the overall power consumed in each of the operation modes differ drastically from what was shown in the previous results (Tables 1 and 2), it is important to point out that the power consumption values reported here include additionally activity of CPU and other parts of the laptop (platform) required to operate the WLAN interface. What can be seen, again, is that for the best NIC (Intersil) power spent on transmission in 802.11g mode is comparable to that spent in 802.11b mode, resulting in huge possible power savings.

The second of the reported articles [11] provides much lower precision of power consumption measurements and thus much less reliable data. Moreover, the results for uplink transmission are missing.

3.4 Access Points (APs)

APs are expected to consume more power than NICs. Tables 4–10 contain total AP power consumption regardless of the operational mode (idle, RX or TX), whereas power consumption related to the specific operational mode is shown in Table 11. Information about devices produced by the same manufacturer (Aruba, Cisco, HP, EnGenius, INTELLINET and Trendnet) is collected in Tables 4–9. Remaining vendors are grouped in Table 10. The data reported for APs, apart from 802.11 standards and production year (as in Section 3.3 for NICs), contains also the information about the number of radios, bands, wireless inputs and outputs (MIMO). Additional remark is made for each AP, whether PoE (802.3af) and/or PoE+ (802.3at) is supported. In case power consumption data for various versions of AP (single or dual-band, single or dual-radio) belonging to the same family is available, the dual version is reported (e.g., [60]). Maximum number of antennas is reported, whenever such data is available.

Capacity of an AP is an important factor, since it determines the amount of power spent by an AP processing a unit of traffic (coming in and going out from any interface). However capacity of APs is reported only in [17]. Table 11 summarizes this information providing also the data about AP power consumption in various operating modes.

Table 4: Power consumption of Aruba APs in W

Device	802.11 stand.	Prod. year	Power [W]
Aruba AP-68 and AP-68P [61]	b/g/n (2x2 MIMO, single-radio, single-band)	2011	8 (12 VDC, 802.3af supported)
Aruba AP-92 and AP-93 [62]	a/b/g/n (2x2 MIMO, single-radio, dual-band)	2011	10 (12 VDC, 802.3af supported)
Aruba AP-105 [63]	a/b/g/n (2x2 MIMO, dual-radio, dual-band)	2011	12.5 (12 VDC, 802.3af supported)
Aruba AP-120 and AP-121 [64]	a/b/g/n (3x3 MIMO, single-radio, dual-band)	2011	12.5 (5 VDC, 802.3af and 802.3at and PoE+ supported)
Aruba AP-124 and AP-125 [14]	a/b/g/n (3x3 MIMO, dual-radio, dual band)	2011	16 (5 VDC, 802.3af and 802.3at and PoE+ supported)

Continued on next page

Table 4 – continued from previous page

Device	802.11 stand.	Prod. year	Power [W]
Aruba AP-125 [17]	n (3x3 MIMO, dual-radio, dual band)	2009	10.6 (Active Mode[3])

Table 5: Power consumption of Cisco APs in W

Device	802.11 stand.	Prod. year	Power [W]
Cisco Aironet 1100 Series AIR-AP1121G-x-K [65]	b/g (integrated antenna, single-radio, single-band)	2006	4.9 Root Mean Square (RMS) (PoE supported)
Cisco Aironet 1200 Series AIR-AP1231G-x-K9 [60]	a/b/g (up to two antennas, dual-radio, dual-band)	2006	13 (PoE supported)
Cisco 521 Wireless Express AIR-AP521G-x-K9 [66]	b/g (integrated antenna, single-radio, single-band)	2008	9.9 (802.3.af supported)
Cisco Aironet 1130AG AIR-AP1131AG-x-K9 [67]	a/b/g (integrated antenna, dual-radio, dual-band)	2009	12.2 (802.3af supported)
Cisco AP 541N AP541N-E-K9 [68]	a/b/g/n Draft 2.0 compliant (2x3 MIMO, single-radio, dual-band)	2010	9.9 (802.3af supported)
Cisco AP 1250 [17]	n (2x3 MIMO single-radio, dual-band)	2009	10.1 (Active Mode[3])
Cisco Aironet 1250 Series AIR-AP1252AG-x-K9 [15]	a/b/g/n (2x3 MIMO dual-radio, dual-band)	2010	18.5 (with two radio modules installed); 12.95 (with one radio module installed) (802.3af supported)[4]

[3]Passing user traffic, 802.11n used, single radio enabled, Wi-Fi Multimedia (WMM) enabled, about 17 dBm transmit power, no encryption, powered by 802.3af ports

[4]Up to 1.5 W can be consumed additionally when using PoE depending on the length of the interconnecting cable. This consideration applies for Cisco Aironet 1250 Series with one radio as well as with two radios.

Table 6: Power consumption of Hewlett-Packard APs in W

Device	802.11 stand.	Prod. year	Power [W]
HP A-WA2612 [69]	a/b/g/n (3x3 MIMO, 3 integrated antennas, single-radio, dual-band)	2010	10 (802.3af supported)
HP A-WA2620AGN [69]	a/b/g/n (2x3 MIMO, 6 integrated antennas, dual-radio, dual-band)	2010	13 (802.3af supported)
HP A-WA2610E-AGN [69]	a/b/g/n (3x3 MIMO, 3 integrated antennas, single-radio, dual-band)	2010	13 (802.3af supported)
HP A-WA2620E-AGN [69]	a/b/g/n (3x3 MIMO, 6 integrated antennas, dual-radio, dual-band)	2010	16 (802.3at supported)
HP A-WA2110-AG [70]	a/b/g (2 external antennas, single-radio, dual-band)	2010	6 (802.3af supported)
HP A-WA2220-AG [70]	a/b/g (2 external antennas, dual-radio, dual-band)	2010	10 (802.3af supported)
HP E-M110 [71]	a/b/g (2 external antennas, single-radio, dual-band)	2010	5 (5 VDC, 802.3af supported)
HP E-MSM310/ E-MSM310-R7HP/ E-MSM313 [72, 73]	a/b/g (2 external antennas, single-radio, dual-band)	2010	6.5 (5 VDC, 802.3af supported)
HP E-MSM320/ E-MSM325 [72]	a/b/g (4 external antennas, dual-radio, dual-band)	2010	8.6 (5 VDC, 802.3af supported)
HP E-MSM335 [72]	a/b/g (6 integrated antennas, triple-radio, dual-band)	2010	12 (802.3af supported)
HP E-MSM317 [74]	b/g (2 integrated antennas,single-radio, single-band)	2010	6 (802.3af supported)
HP E-MSM410 [75]	a/b/g/n (3 integrated antennas, single-radio, dual-band)	2009	8 (802.3af supported)
HP E-MSM422 [75]	a/b/g/n (3x3 MIMO, 6 integrated antennas, dual-radio, dual-band)	2009	12 (802.3af supported)
HP V-M200 [76]	a/b/g/n (3x3 MIMO, single-radio, dual-band)	2010	8.4 (802.3af supported)

Continued on next page

Table 6 – continued from previous page

Device	**802.11 stand.**	**Prod. year**	**Power [W]**
HP E-MSM430/E-MSM460 [77]	a/b/g/n (6 integrated antennas, dual-radio, dual-band)	2010	12.9 (802.3af supported)
HP E-MSM466 [77]	a/b/g/n (6 external antennas, dual-radio, dual-band)	2010	12.9 (802.3af supported)

Table 7: Power consumption of EnGenius APs in W

Device	**802.11 stand.**	**Prod. year**	**Power [W]**
EnGenius EOA3630 [78]	b/g (1 external antenna, unspecif. radio, single-band)	unspecif.	14.4 (24 VDC, 802.3af supported)
EnGenius EOR7550 [79]	a/b/g/n (unspecif. MIMO, 1 integrated antenna, dual-radio, dual-band)	unspecif.	18 (48 VDC, 802.3af supported)
EnGenius EOC2611P [80]	b/g (1 integrated antenna, unspecif. radio, single-band)	unspecif.	14.4 (24 VDC, 802.3af supported)
EnGenius EOC5611P [81]	a/b/g (1 integrated antenna, unspecif. radio, dual band)	unspecif.	24 (24 VDC, 802.3af supported)
EnGenius EAP-3660 [82]	b/g (1 integrated antenna, unspecif. radio, single-band)	unspecif.	18 (48 VDC, 802.3af supported)
EnGenius EAP9550 [83]	b/g/n (2x2 MIMO, 2 integrated antennas, unspecif. radio, single-band)	unspecif.	16 (48 VDC, 802.3af supported)
Engenius ECB3500 [84, 85]	b/g (2 antennas, unspecif. radio, single-band)	2009	12 (12 VDC, 802.3af supported)
EnGenius ECB9500 [86]	b/g/n (unspecif. MIMO, 3 external antennas, unspecif. radio, single-band)	unspecif.	18 (48 VDC, 802.3af supported)
EnGenius ENH200 [87]	b/g/n (2 integrated antennas, unspecif. radio, single-band)	unspecif.	24 (24 VDC, 802.3af supported)

Table 8: Power consumption of INTELLINET APs in W

Device	802.11 stand.	Prod. year	Power [W]
INTELLINET 524704 [88]	b/g/n (1 external antenna, unspecif. radio, single-band)	unspecif.	4 (5 VDC)
INTELLINET 524711 [89]	b/g/n (2x2 MIMO, unspecif. radio, single-band)	unspecif.	3.5 (48 VDC 802.3af supported)
INTELLINET 524728 [90]	b/g/n (2x2 MIMO, unspecif. radio, single-band)	unspecif.	4 (5 VDC)
INTELLINET 524735 [91]	b/g/n (2x2 MIMO, unspecif. radio, single-band)	unspecif.	4 (5 VDC 802.3af supported)

Table 9: Power consumption of Trendnet APs in W

Device	802.11 stand.	Prod. year	Power [W]
Trendnet TEW-637AP [V2.0R] [92]	b/g/n/e (unspecif. MIMO, 2 external antennas, unspecif. radio, single-band)	2010	6 (12 VDC)
Trendnet TEW-638PAP (V1.0R) [93]	b/g/n/e (unspecif. MIMO, 2 external antennas, unspecif. radio, single-band)	2010	3.12 (12 VDC, 802.3af supported)
Trendnet TEW-650AP (V1.0R) [94]	b/g/n/e (1 external antenna, probably single-radio, single-band)	2010	6 (12 VDC)
Trendnet TEW-653AP(V1.0R) [95]	b/g/n (1 integrated antenna, probably single-radio, single-band)	2010	6 (12 VDC, 802.3af supported)
Trendnet TEW-670AP(V1.0R) [96]	a/b/g/n (unspecif. MIMO, 2 integrated antennas, unspecif. radio, dual-band)	2010	5.4 (12 VDC)
Trendnet TEW-690AP (V1.0R) [97]	b/g/n (unspecif. MIMO, 2 integrated antennas, unspecif. radio, single-band)	2010	3.8 (12 VDC, 802.3af supported)

Table 10: Power consumption of APs of various vendors in W

Device	**802.11 stand.**	**Prod. year**	**Power [W]**
Advantech EKI-6311G [98]	b/g (2 antennas, not specified radio, single-band)	unspecif.	12 (802.3af supported, 48 VDC, 0.375 A)
3com wireless 8760 3CRWE876075 [99]	a/b/g (2 antennas, dual-radio, dual-band)	2006	7.2 (PoE 802.3af power with both radios active)
Siemens HiPath 2630/2640 [100]	a/b/g (1 or multiple antennas, dual-radio, dual-band)	2007	10.2 (6 VDC), 9.75 typical (802.3af supported)
Extreme Networks Altitude 450 and Altitude 451 [19]	a/b/g/n (3x3 MIMO dual-radio, dual-band)	2008	12.95, 11 typical (802.3af supported)
typical AP [2, 12]	unspecified	2009	10
Lucent WP-II [12]	b/g	2009	11
Soekris 5501 [12]	b/g	2009	8.2
DLink DI524 [12]	b/g	2009	5
Linksys WRT54G [12]	b/g	2009	7
Linksys WRT54G [101]	b/g (2 antennas, unspecified radio, single band)	2007	6
An anonymous AP [13]	a/b/g (2 antennas, dual-radio, dual band)	2009	9
An anonymous AP [13]	a/b/g (2 antennas, dual-radio, dual band)	2009	6
An anonymous AP [13]	a/b/g (2 antennas, dual-radio, dual band)	2009	6
Meru AP320 [16]	a/b/g/n (6 antennas, dual-radio, dual-band)	2010	11.5 - 17 (depending on configuration; ability to disable unused radios via software to lower power consumption; 802.3at supported)
Meru AP320 [17]		2009	8.0 (Active Mode[3])
Buffalo AirStation N-Technology Wireless-N150 High Power WHR-HP-GN [102]	b/g/n (1 antenna, probably single-radio, single-band)	2010	approx. 5.5

Table 11: Power consumption of APs in W in various operating modes

Device	802.11 stand.	Prod. year	Capacity [Mbps]	Power [W]		
				Idle	RX	TX
PRISM Wireless Local Area Network Access Point ISL36356A-APDK [103]	b (supports dual antenna diversity)	2003	unspecified	unspecified	3.87 (7.5 VDC)	5.025 (7.5 VDC)
Aruba AP-125 [17]	n	2009	136	9.4 (ready)	9.4	10.6
Cisco AP1250[5] [17]	n	2009	79	9.2 (ready)	9.2	10.1
Meru AP320 [17]	n	2009	171	4.7 (ready)	6.6	8.0

Since it is difficult to compare measurements provided in data sheets of different vendors, this report analyses separately each family of APs (of a given vendor).

Aruba's APs differ mainly by the number of used radios and bands, which has an influence on the capacity of an AP. One additional radio results in an increase of power consumption from 10 Watts in Aruba AP-93 to 12.5 Watts in Aruba AP-105. Additional support of 3x3 MIMO instead of 2x2 MIMO increases power consumption by further 3.5 Watts (Aruba AP-125 vs. Aruba AP-105).

All Aruba products support the same 802.11 standards. This is not the case for Cisco Aironet APs, what gives the possibility to compare the power consumption of APs supporting 802.11n standard with the APs that do not support it. Power consumption varies between 12.2 Watts for Cisco Aironet 1130AG without 802.11n support and 18.5 Watts for Cisco Aironet 1250 Series with 802.11n support. Furthermore, additional radio module installed on the Cisco Aironet 1250 Series [15] leads to an increase of power drawn by the device from 12.95 Watts to 18.5 Watts.

HP reports quite complete data on their APs (see Table 6). Again, support of the 802.11n results in a noticeable increase of the power consumption. The difference in power consumption between the least power consuming AP (HP E-M110) and the most power consuming AP reaches 11 W.

A similar trend cannot be observed in the EnGenius products (see Table 7). These APs (according to the collected data) consume more power (up to 24 W) than the HP products. The vendor might have taken different objectives than energy-efficiency when designing his products. All the APs of Intellinet and Trendnet support 802.11b/g/n standards and consume comparable amount of power (3.12 - 6 W).

The power consumption values provided in product data sheets are also compared with the measurements available in the literature [12, 13, 17]. It can be observed that all the power consumption values measured in [17] are smaller than these available in product data sheets. The difference reaches up to 9 Watts for the Meru AP320, but that depends on the configuration of the AP. The difference oscillates usually around 3-4 Watts. Linksys WRT54G was the only AP investigated in [12] for which also data sheet information was found [101]. Interestingly, the measured value was higher than the one provided in the data sheet. The difference was just 1 Watt though. The power of three anonymous APs investigated in [13] range between 6 and 9 Watts and go in line with other values reported in Table 10.

Finally, it should be pointed out that according to data collected in Table 11 (mainly [17]), the

[5] One radio was powered up in the Cisco AP1250 AP, while Aruba-AP-125 and Meru AP230 used two radios [17]

power consumption of an AP in the idle state (Meru AP320) is noticeably reduced, in comparison to RX and TX modes[6]. Power saving in idle APs is not a standard nowadays though. Table 11 also shows that power consumption of APs is not directly related to their capacities for the considered devices.

4 Conclusion

This report provides a detailed collection of power consumption data (together with direct references) of various APs and NICs. There is a big variety of WLAN network elements, showing significantly different levels of power consumption, due to the numerous reasons that were reflected in this report, e.g., supported 802.11 standards, manufacturing year, etc. To decrease the huge amount of power these devices consume in total, new products conform to more and more energy-efficient standards. As it was shown in this work, e.g., see Fig. 1 and Table 11, both analyzed WLAN network elements consume most power in the active state (either transmitting or receiving data). Turning these devices into the power saving mode (no usage of the radios) can significantly decrease the amount of power consumed inside the whole WLAN.

Despite huge efforts spent on collecting, understanding and analyzing the reported data, a great part of it is often not comparable, mainly because of unclear or missing measurement information (operation mode, data rate used, etc.). Within the data that can be compared, a separate conclusion should be drawn for each group of network elements (as expected, the APs consume far more power than NICs). From the comparison provided by Novarum [17], it can be concluded that the Meru AP320 is the most efficient among the analyzed APs (highest ratio between consumed power in transmission mode and idle mode). On the other hand, results from the comparison of NICs seem not that clear in the general picture, even with the scope of the observations limited to one particular standard (see Fig. 1).

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