Environmental Impact of IEEE 802.11 Access Points: A Case Study

Biplab Sikdar
Department of ECSE
Rensselaer Polytechnic Institute
Troy, NY 12180 USA
bsikdar@ecse.rpi.edu

ABSTRACT

Wireless local area networks have become an ubiquitous means for network access in both residential and commercial locations over the recent past. Given their widespread deployment, it is of importance to understand their environmental impact and this paper presents a life cycle assessment of the energy intensity of IEEE 802.11 wireless access points. Following a cradle-to-grave approach, we evaluate the energy consumed in the manufacture of access points (including the extraction of raw materials, component manufacturing, assembly, and transportation) as well as during its actual usage. Our results show that the manufacturing stage is responsible for a significant fraction of the overall energy consumption. In light of our findings, increasing the overall lifetime is one of the recommended ways to reduce the environmental impact of access points.

Categories and Subject Descriptors

B.4.1 [**Hardware**]: Input/output and data communications—*Data Communications Devices*; K.4 [**Computing Milieux**]: Computers and society

1. INTRODUCTION

Wireless access for networks at residential, commercial, educational and public places has increased tremendously over the last decade. Among the various available technologies, IEEE 802.11 or WiFi is one of the most most popular means for wireless network access, with the number of its users estimated to be more than 270 million in 2008 [2]. Given the widespread use and popularity of the IEEE 802.11 protocol, it is of interest and importance to investigate the environmental impact of this technology. In this paper we investigate one aspect of the sustainability of the IEEE 802.11 protocol by considering the energy intensity of its access points.

The most common methodology by which users connect to a wireless local area network is to use IEEE 802.11 access points that serve as gateways. The increasing popularity of the IEEE 802.11 protocol in the recent past has thus resulted in an increase in the number of wireless access points manufactured and deployed. IEEE 802.11 wireless cards are also required at the clients to connect to the access points and most computing devices either have them built-in or can use them as an add-on device. In this paper we focus our attention on the access points and evaluate the energy it takes to manufacture and operate them. In addition to quantifying the energy intensity of the access points, this paper aims to analyze and identify which stage in the access point's life cycle has the greatest influence on the environment. Our methodology is applicable to the client side wireless access cards also.

To the best of our knowledge, the sustainability and environmental impact of IEEE 802.11 based wireless networks has not been addressed in literature. Past research has addressed the energy intensity of computer manufacturing where the total energy and fossil fuel consumption of a desktop computer and a cathode ray tube monitor is evaluated [4]. In [5] the life cycle inventory data of various electronic components is calculated in terms of the energy consumption and atmospheric emissions. The material and energy consumption of mobile phones is addressed in [6, 7] while [8] considers the energy consumption of universal mobile telecommunication system (UMTS) and global system for mobile communications (GSM) mobile communication systems. This paper fills the void in existing literature regarding the energy intensity of wireless access using IEEE 802.11.

We use a Life Cycle Assessment (LCA) method to evaluate the environmental impact of IEEE 802.11 access points. Following a cradle-to-grave approach and detailed inventory analysis, the energy used to manufacture and operate such access points is evaluated. Our results are based on evaluating the material weight and the mapping them to the energy required for production, assembly and transportation. Our results show that manufacturing accounts for 70% of the total energy consumption and the remaining 30% comes from the use phase, assuming a one year operational lifetime. For a three year operational lifetime, these numbers change to 43% and 57%, respectively. Thus extension of the usable lifespan of such access points, for example by upgrading, is a promising approach to alleviate their environmental impact.

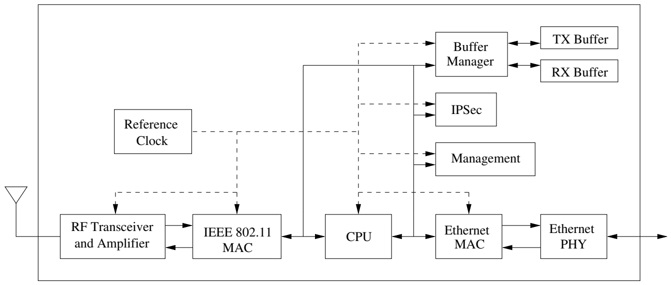

Figure 1: Simplified block diagram of an IEEE 802.11 access point.

The rest of the paper is organized as follows. Section 2 presents an overview of the basic building blocks of an IEEE 802.11 access point. Section 3 presents the energy intensity analysis of an access point and Section 4 concludes the paper.

2. OVERVIEW OF AN IEEE 802.11 ACCESS POINT

The IEEE 802.11 standard [9] covers both the physical (PHY) and the medium access control (MAC) layer of wireless networks. The standard specifies that a network can be configured in two different ways: infrastructure and ad-hoc. In infrastructure mode, an access point is typically connected using an Ethernet (IEEE 802.3) link to a wired network and all wireless nodes communicate to this network through the access point. On the other hand, in an ad-hoc network the computers are brought together to form a network dynamically. The focus of this paper is on infrastructure networks that are based on the use of access points.

A simplified block diagram of an IEEE 802.11 access point is shown in Figure 1 and is based on [1, 3]. The access points have functional blocks for the MAC and PHY layers of both the IEEE 802.11 and 802.3 protocols, transmit and receive buffers that are controlled by a buffer manager, units for management and Internet Protocol Security (IPSec), and a control unit. The access point communicates with the wired network using the Ethernet MAC and PHY functional blocks. These two blocks are responsible for transmitting and receiving Ethernet frames, address checking, cyclic redundancy checking (CRC) and carrier sense multiple access with collision detection (CSMA/CD). The received frames and frames to be transmitted are stored in pre-allocated transmit and receive buffers. The Ethernet MAC functional block and the CPU (depending on the exact architecture of the access point) are also responsible for checksum calculation, and insertion and deletion of Transport Control Protocol/Internet Protocol (TCP/IP) headers. The radio frequency (RF) transceiver and amplifier carry out the IEEE 802.11 PHY operations and its functionality is analogous to that of the Ethernet PHY functional block. Similarly, the functionality of the IEEE 802.11 and Ethernet MAC functional blocks are similar, except that the IEEE 802.11 MAC is based on CSMA with collision avoidance (CSMA/CA). The management functional block is responsible for allowing administrators to setup, repair and maintain the access point while the IPSec functional block is responsible for authenticating and encrypting the IP packets.

For our case study, we used a Linksys WRT54GS v2.1 access point. The access point has two antennas and also includes 5-port Ethernet hub. The access point uses two memory chips: a 256MB double data rate synchronous dynamic random access memory (DDR SDRAM) and a 8MB flash memory. The access point also uses two separate integrated circuits (ICs) for the Ethernet switch and the IEEE 802.11 router. In addition, three different clocks are used: one by the Ethernet functional blocks, one by the IEEE 802.11 MAC and one by the IEEE 802.11 PHY.

3. ENERGY INTENSITY OF AN ACCESS POINT

We use a LCA approach to evaluate the energy intensity of an access point. The LCA approach quantitatively evaluates the energy consumed by a product over its life-cycle, from the materials production stage to its final disposal. Using the Linksys WRT54GS v2.1 access point as a case study, we divide the life-cycle of an IEEE 802.11 access point into two phases: manufacture and usage. We assume that at the end of the use phase, the access point is discarded and not recycled. While this assumption is pessimistic, it is not unrealistic since recent statistics show that only 13.6% of electronic waste is recycled in the USA and the rest ends up in landfills or incinerators [10].

The rest of this section elaborates on the LCA analysis for our calculation of the energy intensity of an access point by considering the energy consumed during the manufacturing process and the actual use.

3.1 Energy Consumed During Manufacturing

The manufacturing process for an IEEE 802.11 access point consists of the following steps, each of which contributes to the energy intensity:

- *Raw material extraction and processing:* The first step in the manufacturing process is the extraction, processing and refining of raw materials that are required for the manufacturing of the various components that constitute the access point. For electronic and computing devices, while precious metals constitute only a small percentage of the overall device weight, the energy needed to extract and refine them is typically far larger than that required for other materials.
- *Component manufacturing:* In this step the raw materials are used to manufacture the individual components inside an access point. The electronic components needed by an access point can be classified as either passive (such as resistors and capacitors) or active (such as semiconductor chips), each having different energy intensities. In addition, there are a number of other components such as connectors, cables, switches etc.
- *Assembly:* The assembly phase starts with the soldering of the electronic components on a printed wiring board. All other components such as antennas and casing are then assembled and the product is tested. The major sources of energy consumption in this phase is the electricity required for lighting, air conditioning and machinery, usually in that order [6].

- *Packaging and transportation:* The energy consumed for packaging and transportation is primarily dependent on the weight and dimensions of the product, the distance traveled, and the means of transportation. The Linksys WRT54GS v2.1 access point was made in China. We assume that the product was manufactured in the Guangzhou province (with a large concentration of electronics industry) and transported using a truck to Hong Kong (150 km), from where it was put in a cargo ship to New York City (20100 km). Finally, the access point was transported in a truck from New York City to Troy, New York (250 km) where it was purchased and used.

To evaluate the energy intensity of each stage of the manufacturing process, we first conduct a detailed inventory analysis to evaluate the weight (or surface area in case of semiconductor devices and printed wiring boards) of the various components that constitute the access point. Then, existing databases are used to evaluate the energy intensity of each component in each stage of the manufacturing process.

The Linksys WRT54GS v2.1 access point can be considered to be made of three parts: the access point itself, the antennas, and the power supply. The list of all components and their weights is given in Table 1. For the ICs and transistors, we also list the surface area of the silicon wafers (i.e. die size) used inside the chips (since the LCA database provides the energy intensity in terms of the area). However, since only the external area of an IC is measurable and most data sheets do not provide die size dimensions, we assumed that the die area is 40% of the IC area. Typical IC packaging technologies such as chip scale packaging (CSP), ball grid array (BGA), shrink small-outline package (SSOP) and thin-SSOP (TSSOP) have a die size that is between 30-80% of the IC area [11, 12], and we use a conservative estimate in this range. Also, the die size of a power transistor is assumed to be 11.07 mm^2 [13] and that of other discrete transistors is assumed to be 0.5 mm^2 [14].

The majority of the per unit energy cost values in Table 1 were obtained from the LCA database developed by Chalmers University of Technology, Sweden [15] (available at `http://www.cpm.chalmers.se/CPMDatabase`). In the absence of relevant data, the material cost for various active and passive electronic devices is assumed to be the same, as in [6, 5]. Also, for any component for which data was not explicitly available (e.g. surface mounted inductors), data corresponding to "other electronic components" from [15] was used. Finally, we note that the material and component costs for diodes is combined in a single entry, as given in the LCA database [15].

The total energy intensity of the manufacturing phase is shown in Table 2. This table combines the results from Table 1 for the raw materials and components with the energy intensity of the assembly and transportation stages. For the transportation stage, it was assumed that the final shipping weight after packaging was 750 g.

3.2 Energy Consumed During Usage

We conducted measurements on a Linksys WRT54GS v2.1 IEEE 802.11 access point under different traffic loads to evaluate the power consumption of an access point in the use stage. Our measurements show that the current drawn from the power supply was constant at 150.25 mA at all loads and the supply voltage was 14.78 V. Considering a power supply efficiency of 80% [20], the per day energy consumption of the access point is 66.62 Wh, assuming a typical usage scenario where the access point always stays powered on (e.g. in academic institutions and many residences). Thus the total power intensity of the access point is 24316.30, 48632.60 and 72948.90 Wh for usage lifetimes of one, two and three years, respectively.

Table 2: Energy intensity of manufacturing phase. The values for the raw material extraction and component manufacturing stages are obtained from Table 1. The unit costs for the assembly stage are expressed in Wh/g while those for the transportation (Trans) stages are expressed in Wh/g-km.

Stage	Weight/ Distance	Unit cost	Source	Energy (Wh)
Materials and components	588.26 g	-	-	45018.18
Assembly	588.26 g	15.90	[6]	9353.33
Trans: truck	400 km	0.00044	[19]	132.00
Trans: ship	20100 km	0.000068	[18]	1025.10
Total				55528.61

3.3 Discussions

The results of the previous two subsections show that the manufacturing stage accounts for a significant portion of the overall energy intensity of an IEEE 802.11 access point. The energy consumed during manufacturing accounts for 69.6%, 53.3% and 43.2% of the overall energy consumption for product lifetimes of one, two and three years, respectively. While recycling is an option to mitigate the environmental impact of manufacturing, they only recover a fraction of the used raw materials in the components, while assembly and transportation energies are never recovered. Thus, extending the usable lifetime of the access points, for example by upgrades, is an attractive option to reduce the environmental impact of wireless networks.

As a caveat, we would like to add that there are a number of assumptions made in this paper (e.g. no recycling, power supply efficiency values etc.), which may not be valid in all cases. However, it is fairly straightforward to accommodate alterations. Also, the absence of data (e.g. manufacturing costs for SM inductors) in some cases forced us to make approximations. While such approximations cannot be avoided in the absence of data, since only a small fraction of the components were affected, we do not expect the errors to be significant.

4. CONCLUSIONS

This paper presented an LCA based study to evaluate the energy intensity of an IEEE 802.11 access point from cradle-to-grave. The energy consumed in the manufacturing phase was computed using a detailed inventory analysis and that in the use phase was evaluated experimentally in an operational network. Our results show that the energy consumed in the manufacturing phase is a significant fraction of the

Table 1: Parts inventory of the Linksys WRT54GS v2.1 access point (SM: surface mounted, HM: hole mounted, LED: light emitting diode, PWB: printed wiring board, BNC: Bayonet Neill-Concelman)

Access Point								
Component	Number	Total Weight (g)	Area (mm^2)	Material (Wh/g)	Component cost		Source(s)	Energy intensity (Wh)
					(Wh/g)	cost (Wh/mm^2)		
SM resistors	121	0.54	-	4.88	95.99	-	[6, 15]	54.47
SM capacitors	188	2.72	-	4.88	109.86	-	[6, 15]	312.09
SM inductors	15	0.42	-	4.88	48.00	-	[6, 15]	22.21
HM capacitors	5	4.14	-	4.88	11.88	-	[6, 15]	69.39
HM inductors	7	10.12	-	4.88	6.51	-	[6, 15]	115.27
Si ICs	18	4.63	520.20	4.88	24.11	40.27	[6, 15]	21082.68
Diodes	17	1.53	-	386.59		-	[15]	591.48
LED housing	8	1.64	-	22.5	0.86	-	[16, 15]	38.31
Coaxial cable	1	2.68	-	5.71	0.83	-	[15]	17.53
PWB	1	82.36	21957.75	4.88	-	0.34	[6, 15]	7867.55
Connectors	3	24.57	-	61.41	6.51	-	[15]	1668.79
Screws	3	2.00	-	14.85	7.78	-	[15]	45.26
Al cover	1	1.76	-	13.23	0.75	-	[17, 15]	24.61
BNC connectors	2	55.32	-	15.92	5.08	-	[15]	1161.72
Switches	2	1.23	-	61.41	6.51	-	[15]	83.54
Clock crystals	3	1.11	-	4.88	6.51	-	[6, 15]	12.64
Plastic casing	1	207.50	-	22.5	0.86	-	[16, 15]	4847.20
Total								38014.74
Antennas								
Coaxial cable	2	3.15	-	5.71	0.83	-	[15]	20.60
BNC connectors	2	28.51	-	15.92	5.08	-	[15]	598.71
Plastic casing	2	28.34	-	22.5	0.86	-	[16, 15]	662.02
Total								1281.33
Power Supply								
SM resistors	16	0.14	-	4.88	95.99	-	[6, 15]	14.12
SM capacitors	5	0.05	-	4.88	109.86	-	[6, 15]	5.74
HM resistors	1	0.54	-	4.88	5.16	-	[6, 15]	5.42
HM capacitors	4	10.29	-	4.88	11.88	-	[6, 15]	172.46
HM inductors	3	21.41	-	4.88	6.51	-	[6, 15]	243.86
Si ICs	2	0.57	39.10	4.88	24.11	40.27	[6, 15]	1591.08
Transistors	1	0.16	0.50	4.88	200.00	23.13	[6, 15]	44.35
Power transistors	2	3.56	22.14	200.00	24.11	23.13	[6, 15]	1309.93
Diodes	3	0.25	-	386.59		-	[15]	96.65
PWB	1	6.00	2479.00	4.88	-	0.34	[6, 15]	872.14
Jumpers	4	0.13	-	8.72	5.71	-	[15]	1.88
Fuses	1	0.27	-	4.88	6.51	-	[15]	3.08
Foam	3	1.60	-	0.32	28.16	-	[15]	45.57
Heat sink	2	6.59	-	13.23	0.75	-	[17, 15]	92.13
Screws	2	0.85	-	14.85	7.78	-	[15]	19.24
Wire	1	30.00	-	5.71	6.51	-	[15]	366.60
Plug pins	2	2.00	-	15.92	5.08	-	[15]	42.00
Plastic casing	1	37.00	-	22.5	0.86	-	[16, 15]	864.32
Total								5722.11
Grand Total								45018.18

overall energy intensity of the access point. Mechanisms to increase the overall lifetime of the access point is thus an attractive way to decrease the environmental impact and energy footprint of the access points.

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