Network Electricity Use Associated with Wireless Personal Digital Assistants

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Abstract: This article examines the widely cited claim that the network electricity use associated with a wireless personal digital assistant (PDA) is equal to the electricity consumed by a refrigerator. It compiles estimates of the data flows of wireless PDAs and related networks and allocates network and phone system electricity use based on these estimates. It also conducts sensitivity analyses to verify the robustness of these calculations. This analysis demonstrates that the network electricity use associated with a wireless PDA cannot equal that of a typical refrigerator, even under the most extreme assumptions. Our best-estimate case shows network electricity use for wireless PDAs of 0.5 kW·h/year, and therefore claims that wireless PDAs use as much electricity as a refrigerator are too high by more than a factor of 1,000. Even in our upper-limit assessment, the electricity used by a new U.S. refrigerator is about 100 times greater than the network electricity use associated with a wireless PDA.

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Introduction

Over the past 5 years, several erroneous claims about how much electricity is used by office equipment have been widely cited as factual. The most commonly circulated assertions include the following:

1. The Internet uses about 8% of all U.S. electricity.
2. Computers and networking equipment (including the Internet) use 13% of all U.S. electricity.
3. This total will grow from 13% to 50% of all U.S. electricity use by 2010.
4. The networking electricity use associated with a wireless personal digital assistant (PDA) is equal to that of a refrigerator (1,000–2,000 kW·h per year).

The first three of these claims originated in an article by Peter Huber and Mark Mills in *Forbes* in May 1999 (Huber and Mills 1999), based on a report written by Mills (1999). These articles have been analyzed and refuted elsewhere (Koomey et al. 1999, 2002; Koomey 2000; Baer et al. 2002; Kawamoto et al. 2002; Roth et al. 2002). These refutations found, without exception, that Huber and Mills vastly overestimated electricity use associated with computers and network equipment, in some cases by more than an order of magnitude. Nonetheless, Huber and Mills continue to assert these claims (Huber and Mills 2003; Mills and Huber 2003).

The fourth claim, put forth by Mills, has not been examined in the peer-reviewed literature until now. This assertion has been widely cited in the past few years, appearing in the *New York Times* (Anderson 2001), the *Wall Street Journal* (Huber and Mills 2000), and other major U.S. news publications. Like the other three claims, it has been used to support the notion that electricity demand growth, driven by the allegedly explosive growth in the electricity used by information technology, will exceed recent historical norms. The authors then conclude with some policy prescription, generally involving building more utility infrastructure of the type favored by whoever is citing the statistic. For example, the director of the Energy Research Center at Columbia University wrote in an editorial in the *New York Times* (Anderson 2001) that ‘‘according to one study, a Web-enabled Palm Pilot uses as much electricity as a heavy-duty refrigerator.’’ He then proceeded to recommend big investments in the utility grid. Of course he also had other good reasons for supporting this argument, but the wireless PDA claim was prominently displayed.

It is important to get the numbers right in matters that affect public policy and business investment. Virtually all business and policy decisions today are based on quantitative data, and no good can come of incorrect information being widely accepted. The U.S. economy is still recovering from the hype and delusions that pervaded the Internet boom (Dreazen 2002), and the wide initial acceptance of the urban legend that office equipment uses a huge

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amount of electricity was in part a product of those delusions (Koomey 2001, 2003; Koomey et al. 2002).

These claims were especially pernicious because they were accepted and repeated by leaders in business, government, and academia. *Forbes* itself lent credibility to the argument simply by publishing it. The trade press and the popular media repeated the key claims in the *Forbes* article, often without citing a source, thus enshrining the erroneous statistics as ‘‘common knowledge.’’ Two major industry organizations and politicians from both political parties quoted the statistics, investing their credibility in perpetuating the problem (most later distanced themselves from these assertions). Finally, at least six major investment banks gave stock recommendations based on these estimates (Anderson et al. 2000; Feygin et al. 2000; Niles et al. 2000; Pencak et al. 2000; Stephens, Inc. 2000; Tirello et al. 2000), and investors surely lost money because of this flawed advice.

This article completes the peer-reviewed assessment of the work of Huber and Mills on the electricity used by office equipment, in hopes that this episode will serve as a well-documented cautionary tale for decision makers relying on ‘‘gee-whiz’’ statistics to support their plans. In addition, the compilation of data necessary for correcting these misleading statistics represents a significant methodological advance over previous efforts, and it will prove useful for other analysts attempting to conduct related analyses. To our knowledge, this article represents the first systematic attempt to allocate network electricity use in proportion to data flows, and others should emulate this approach. For example, assessments of the network electricity use associated with data flows of any kind (e.g., digital music or text) can use the methods and data described here.

This article first describes the methodology used to estimate the amount of electricity associated with wireless PDAs and then presents the results and discusses their implications. It also describes further research and conclusions.

Methodology and Data

The author of the claim about the amount of network electricity associated with wireless devices never published his methodology. We requested a copy of the documentation for this claim from him but have received no response. We therefore created an appropriate methodology from first principles using available data, and we describe it below.

One of the most widely cited examples of how the wireless PDA assertion appeared was contained in an article by Mills (2001) in the *American Spectator*: ‘‘Consider a tiny Palm Pilot or Compaq PDA with wireless Internet access. Today the electricity consumed, not by the Palm itself, but in the invisible networks linking that Palm to and through the vast labyrinth of networked IT hardware, totals 1,000 to 2,000 kW·h/year (pro-rated for each user’s share of the data hotels and beyond). That’s what a household refrigerator consumes.’’ We focus here on the exact statement of Mills’s claim and examine the network electricity use associated with a wireless personal digital assistant in 2000, which was the latest year for which Mills could have analyzed network electricity use for wireless PDAs before making the claim in late 2000 and early 2001.

Computer networks are used to transmit data from many sources. We consider three parts of the network here:

1. The Internet, defined as the public backbone and the networks associated with that backbone;
2. The traditional phone system, including local, intrastate, and interstate long distance services; and

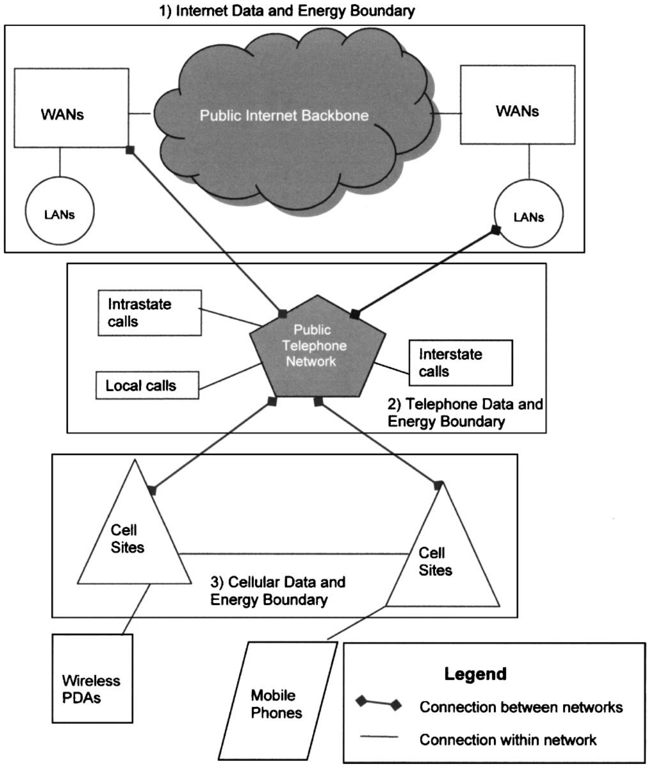

Fig. 1. Energy and data flow boundaries used for network calculations in this study

3. The cellular network, for wireless voice and data communications.

Following a long tradition in end-use analysis (and apparently in accord with Mills’s approach, where he says that networked electricity use is ‘‘pro-rated for each user’s share of the data hotels and beyond’’), we chose to allocate electricity use for the network as a function of the service delivered (data transmission). By estimating the annual data flow for a typical wireless PDA circa 2000, we can then assign some fraction of the total network electricity to that PDA, based on the ratio of the PDA data flow to the total data flow for each major network component (i.e., the Internet, the standard telephone system, and the cellular system).

We assume that all of these networks will be used for all PDA data flows, which is a simplifying assumption. For example, if 100 kB of data are transferred from the wireless PDA, we assume that 100 kB flows over the cellular network, 100 kB travels through the standard telephone network (because that system often provides the link between the cellular systems and the Internet), and 100 kB proceeds through the Internet.

Some parts of existing networks will never transmit PDA data, and both the data flows and electricity use associated with those segments should in principle be omitted from the calculation. Whether this omission would increase or decrease the amount of network electricity allocated to the wireless PDA would depend on whether the average electricity intensity of these segments (in kW·h/MB) was higher or lower than the remaining portions of the network. There is no obvious way to determine which way a more accurate calculation would lead, so we assume for now that the average electricity intensity of the segments not used by the PDA is the same as for the rest of the network.

The network system boundaries we choose are summarized in Fig. 1. In each case, we determined the data flows through the system and the electricity use associated with that part of the system, and we then allocated network electricity use based on the fraction of data flows associated with each PDA.

Wireless PDA

Our focus is on the year 2000, and for that reason the Palm VII (introduced in May 1999) and Palm VIIx (introduced in June 2000) wireless devices are the most representative of conditions at the time these claims surfaced. These PDAs used two AAA nonrechargeable alkaline batteries and had only very simple Web clipping and e-mail capabilities, thus limiting the amount of data likely to flow through them.

It is important to note that these PDAs were the dominant ones in the very tiny market that existed for such wireless devices in 2000. We rely on data for them taken from Palm, which had about two-thirds of sales for all PDAs in 2000. The number of Palm VII and VIIx devices connected to Palm's network was 40,000 in January 2000, 110,000 in July 2000, and 180,000 in January 2001, and this growing population comprised the sample for the data flows presented below.

Direct Electricity Use

We ignore direct electricity use for the PDA because it is beyond the scope of Mills's claim about network electricity use.

Data Flows

We considered two scenarios of PDA data transmission. The first scenario represents average wireless PDA usage in 2000. For this scenario we obtained from Palm the average monthly data transmitted per active wireless PDA user on the Palm network, averaged across the tens of thousands of users on that network in 2000. This average totals 0.098 MB (100 kB) per month in 2000 (F. Soriano, Palm, Inc., personal communication, September 29, 2003). [Following standard usage in the computer industry, 1 MB$=2^{20}$ (or 1,048,576) bytes, and 1 kB$=2^{10}$ (or 1,024) bytes. These conventions differ from standard metric usage for M and k (where M=1,000,000 and k=1,000).]

The second scenario is an upper bound to wireless PDA data flows. Because of the limitations of Palm's database-tracking system in place before October 2001, the company did not have data available for 2000 in a form that would allow us to calculate an upper bound. Instead, they were able to report on the average data transmitted per month by the most active 1% of users on the Palm VII/VIIx network in October and November of 2001, which was 1.4 MB/month. Based on this information, Palm believes that data flows for the top 1% of users in 2000 would be between 1 and 1.5 MB/month (F. Soriano, Palm, Inc., personal communication, September 30, 2003). We used 1.5 MB/month in our calculations as an upper limit.

It is important to understand that the wireless PDAs existing in 2000 were capable of only very limited data transfers, and the data flows for 2000 are not representative of the significantly greater data flows of new wireless PDA models introduced to the market even two years later. Because the claim about the wireless PDA originated in 2000, our focus is on that year, and our method requires comparing year 2000 data flows for the wireless PDA with data flows of the relevant networks in that same year. Both wireless PDA and network data flows have been increasing rapidly as new technologies are introduced, and it is not clear which is now growing faster, but that uncertainty does not affect the validity of the year 2000 comparison.

Table 1. Network and Phone System Direct Electricity Use

Network	Electricity use (TW·h/year)
Cellular network	2.4[a,b]
Telephone system	
Transmission	1.8[a]
Public telephone network	1.0[a]
PBX	1.0[a]
Total phone system	3.8
Internet, including WANs	
Servers of all types	10.2[a,c]
Routers	1.1[a]
Data storage	1.5[a]
WAN switches	0.15[a]
LAN switches	3.3[a]
Hubs	1.6[a]
Uninterruptible power supplies	5.8[a]
Total Internet	24.0
Totals	30.0

[a] Taken from Table 5-1, Roth et al. (2002).

[b] Roth et al. (2002) estimates for cellular phone electricity use adjusted upwards by 4% to reflect larger number of cellular sites (see text).

[c] Includes electricity used by all types of servers, including low end, workhorse, midrange, and high end.

Note: Electricity use does not include that for cooling, ventilation, or auxiliary equipment.

Data and Telephone Networks

Electricity Use

To calculate the direct electricity used by the Internet and phone networks in Table 1, we used consumption estimates directly from Table 5-1 of Roth et al. (2002), only modifying the estimates for cellular network slightly. For the Internet, we included electricity used by servers of all types: local and wide area network switches (LANs and WANs), routers, hubs, data storage, and uninterruptible power supplies (personal computers and laptops are not included because we are focusing on network electricity use). For the telephone system, we included electricity from telephone transmission, the public telephone network, and private branch exchanges (PBXs). For the cellular system, we included electricity from cellular sites but did not include electricity from mobile phone handsets because we focused on the network electricity associated with a wireless PDA.

Cellular network electricity use is given by Roth et al. (2002) as 2.3 terawatt·hours (TW·h) per year in the United States in 2000, based on a three-level characterization of cellular sites in the United States. Roth's average power per site is 2.65 kW, and the total number of cell sites is given as 100,000 at the end of 2000. The Cellular Telecommunications and Internet Association (CTIA 2003) says there were 104,288 total installed cell sites at the end of 2000, so the Roth et al. (2002) estimate for total sites is about 4% too low. We adjust Roth's total electricity use upward by that amount, yielding 2.4 TW·h/year.

For purposes of estimating network electricity use, we erred on the side of being more inclusive, with the understanding that this approach would result in an overestimate of network electricity use associated with the wireless PDA. For example, we in-

Table 2. U.S. Data and Telephone Traffic in 2000

Network	Traffic (TB/month)	Traffic (TB/year)
Cellular phone system[a]	1,500	18,000
U.S. voice—long distance (interstate toll)[b]	53,000	636,000
U.S. voice—local and intrastate toll calls[c]	377,000	4,524,000
U.S. voice—total[d]	430,000	5,160,000
Internet[e]	20,000	240,000
Other public data networks[f]	3,000	36,000
Private lines[f]	6,000	72,000
Total data networks	29,000	348,000

Note: In all cases, 1 TB $=2^{40}$ bytes.

[a] Cellular phone system traffic taken from Coffman and Odlyzko (2001), p. 8.

[b] Long distance traffic taken from Coffman and Odlyzko (2001), Table 1.2.

[c] Local and intrastate toll call traffic calculated as the difference between long distance and total traffic.

[d] Total U.S. voice traffic calculated based on long distance from Coffman and Odlyzko (2001), Table 1.2. and from FCC (2003), which indicates that long distance traffic (measured in dial equipment minutes or DEMs) totalled 12.3% of all DEMs in 2000.

[e] Internet data traffic is taken to be the lower end of the range of 20,000 to 35,000 TB/month, from Coffman and Odlyzko (2001), Table 1.2.

[f] Traffic on other public networks and private data lines taken from Coffman and Odlyzko (2001), Table 1.2. We assume the lower end of the private-line traffic (high end is 11,000 TB/month).

cluded electricity used by data storage devices, even though that electricity use is only peripherally related to data flows, and we included PBXs, even though their electricity use is in large part related to internal communications within firms that are not associated with data flows from wireless PDAs.

Finally, we included cooling, ventilation, and auxiliary electricity use associated with phone system and network equipment by multiplying all electricity use estimates for cellular, telephone, and Internet equipment by a factor of 2. This doubling of electricity use roughly characterizes the additional loads necessary in large data centers and telephone central offices for keeping the networks operating (Mitchell-Jackson et al. 2003). This method probably overestimates electricity use because not all network devices require this level of auxiliary equipment, and this factor of 2 includes uninterruptible power supplies, which are counted explicitly in the data from Roth et al. (2002). We ignore this discrepancy but note that it probably results in an overestimate of network electricity use associated with the wireless PDA.

Data Flows

Table 2 shows data flows for the three parts of the network relevant to this article: the cellular phone system, the standard telephone system (also known colloquially in the industry as the ‘‘plain old telephone system’’ or POTS), and the Internet. Coffman and Odlyzko (2001, p.8) estimate cellular phone traffic at 1,500 TB/month (1 TB $=2^{40}$ bytes) at the end of 2000. The cellular phone system has by far the smallest traffic of the three major parts of the network.

Coffman and Odlyzko (2001, Table 1.2) estimate long distance traffic at the end of 2000 at 53,000 TB/month, but they do not include data flows for local and intrastate phone traffic. The Federal Communications Commission (FCC 2003) gives historical data on U.S. dial equipment minutes (DEMs), which are a measure of telephone network activity. This source indicates that long distance (interstate toll) DEMs comprised 12.3% of the total phone system traffic in 2000, and local and intrastate toll calls made up the rest. We used these two statistics to estimate total phone system network flows at about 430,000 TB/month (53,000/0.123).

Coffman and Odlyzko (2001, Table 1.2) give data flows for the Internet of between 20,000 and 35,000 TB/month at the end of 2000. We adopt the lower of these figures as a conservatism (a smaller total network flow makes each megabyte of mobile PDA data flow that much more important). We combined data flows from the Internet with those of what Coffman and Odlyzko call the ‘‘other public networks’’ (3,000 TB/month) and the private lines [6,000 TB/month, the lower of the range cited by Coffman and Odlyzko (2001)] to match our system boundary definitions.

Results and Discussion

Principal Results

Table 3 and Fig. 2 summarize our calculations. As noted above, we show two scenarios for the data flows associated with the wireless PDA, the first of which is typical for wireless PDA users generally (referred to here as our best-estimate case), and the second is our upper-bound estimate.

In the best-estimate case, electricity use associated with the network is only 0.5 kW·h/year, with 66% of that total related to the cellular network and 33.6% related to the Internet. The remaining 0.4% is associated with the standard telephone network. In the upper-limit case, network-related electricity totals about 7 kW·h/year, split between the networks in the same proportions as in the best-estimate case.

Comparison to Electricity Used by Refrigerator

Fig. 3 shows data from the Lawrence Berkeley National Laboratory Appliance Efficiency Standards analysis program (S. Meyers, Lawrence Berkeley National Laboratory, personal communication, September 10–11, 2003), which indicates that new refrigerators used about 700 kW·h/year in 2000, while existing refrigerators consumed about 900 kW·h/year. Mills’s estimate of 1,000–2,000 kW·h year is therefore between 11 and 122% too high compared to an existing U.S. refrigerator. This discrepancy turns out to be inconsequential to the final comparison, however.

In the best-estimate case, the direct and indirect electricity used by the PDA is 0.05% of the actual consumption of a U.S. refrigerator existing in 2000 (based on the 900 kW·h/year estimate), while in the upper-limit case, wireless PDA consumption is 0.8% of existing refrigerator electricity use. Mills’s claim about wireless PDA electricity use equaling that of a refrigerator therefore represents an overestimate by a factor of more than 1,000 in the best-estimate case and more than a factor of 100 in the upper-limit case.

Sensitivity Calculations

Koomey et al. (1999) used a top-down approach to calculate electricity used by the standard telephone system of 12 TW·h (including cooling and auxiliary equipment), about a factor of 1.5 larger than Roth et al.’s (2002) estimate when cooling and auxiliary loads are added to that estimate. If we used this estimate instead of Roth et al.’s estimate, the change in results is negligible be-

Table 3. Calculation of Network Electricity Used by Wireless Personal Digital Assistant (PDA) circa 2000

Description	Units	Cellular network	Telephone network	Internet	Total
Network electricity use (including cooling, vent, and auxiliary)	Tw·h/year	4.8[a]	7.6[a]	47[a]	60
Data flows	TB/year	18,000[b]	5,160,000[b]	348,000[b]	5,526,000
Average electricity intensity of data flows	kW·h/MB	0.267	0.001	0.136	0.011
Scenario 1: Average PDA data flows					
Data flow per PDA	MB/year	1.17[c]	1.17[c]	1.17[c]	
Fraction of total data flow		6.2E−11	2.2E−13	3.2E−12	
Network electricity allocated to wireless PDA	kW·h/year	0.30	0.0016	0.15	0.45[e]
as a percentage of electricity used by an existing U.S. refrigerator	*%*				*0.05%*
Scenario 2: Upper limit of PDA data flows					
Data flow per PDA	MB/year	18[d]	18[d]	18[d]	
Fraction of total data flow		9.3E−10	3.2E−12	4.8E−11	
Network electricity allocated to wireless PDA	kW·h/year	4.5	0.02	2.3	6.8[e]
as a percentage of electricity used by an existing U.S. refrigerator	*%*				*0.75%*

[a] Network electricity consumption from Table 1, based on Roth et al. (2002), ⟨http://www.eren.doe.gov/buildings/documents⟩, adjusted upwards by a factor of 2 to reflect cooling, ventilation, and auxiliary equipment loads.

[b] Network data flows taken from Table 2, based on Coffman and Odlyzko (2001), ⟨http://www.dtc.umn.edu/~odlyzko/doc/oft.internet.growth.pdf⟩ ($1\ \text{TB}=2^{40}$ bytes, $1\ \text{MB}=2^{20}$ bytes).

[c] Average PDA data flows based on average data flow of active Palm VII and VIIx users in 2000 of 100 kB/month (Fermin Soriano of Palm, personal communication, September 29, 2003). Excludes inactive owners of Palm wireless devices, i.e., those who own the device and pay for the service but who never use it. The number of Palm VII and VIIx devices connected to Palm's network was 40,000 in January 2000, 110,000 in July 2000, and 180,000 in January 2001, and this growing population comprised the sample for the average data flows for 2000.

[d] Upper-limit PDA data flows based on average data flow of top 1% of active Palm VII and VIIx users in October and November 2001 of 1.4 MB/month. Data for 2000 were not available in a form that would allow calculation of usage for top 1% most intensive users. Based on these data from the end of 2001, Palm believes that data flows for the top 1% of users in 2000 would be between 1 and 1.5 MB/month. We used 1.5 MB/month here as an upper limit (Fermin Soriano of Palm Inc., personal communication, September 30, 2003).

[e] An existing U.S. refrigerator used about 900 kW·h/year in 2000, according to the appliance efficiency standards analysis team at LBNL (S. Meyers, Lawrence Berkeley National Laboratory, personal communication, September 10–11, 2003).

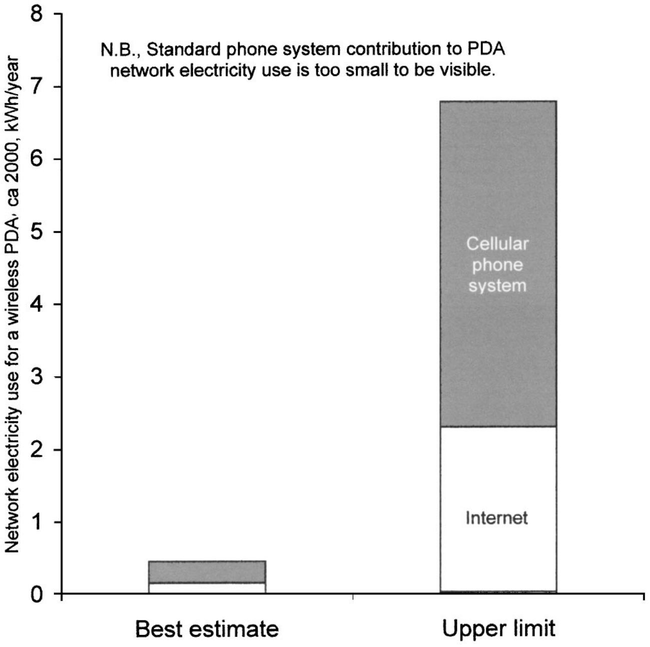

Fig. 2. Direct and indirect electricity use associated with wireless personal digital assistant (PDA)

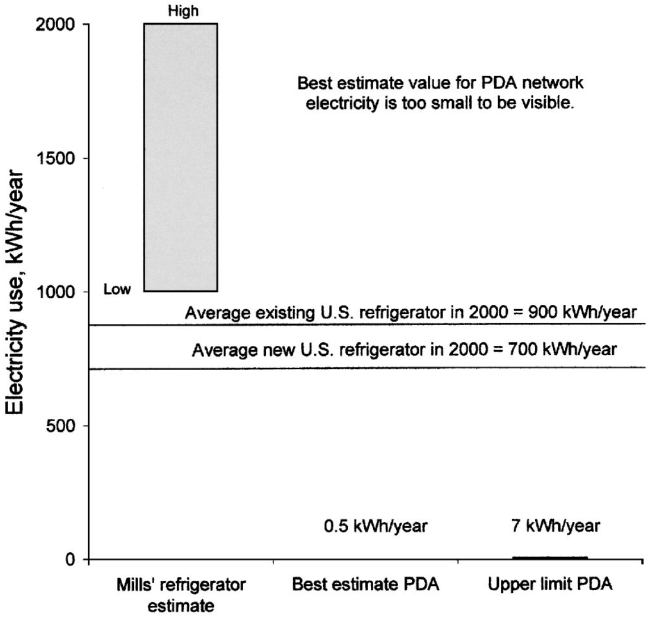

Fig. 3. Comparison of personal digital assistant (PDA) electricity use to that of typical new and existing U.S. refrigerators

cause the telephone system contributes only a tiny percentage of the network electricity associated with a wireless PDA.

Even assuming a telephone system that is able to compress the data flows associated with voice communications by a factor of 10 compared to the standard phone system (perhaps using voice-over Internet protocol (IP) technology and advanced compression), the result would still not change noticeably. Assuming that the wireless PDA data flows did not change, the electricity use associated with the standard phone system in the best-estimate case would then be 0.016 kW·h per year instead of 0.0016 kW·h/year, while in the upper-limit case it would rise to 0.2 kW·h/year. The electricity used by the telephone network was simply not an important contributor to total network electricity used by wireless PDAs in 2000. That relationship may change in the future if data traffic continues to grow more rapidly than voice traffic, but for 2000, it is a firm conclusion.

Future Work

Benefits and Pitfalls of More Complete Life-Cycle Assessment

To most accurately assess the total resource use associated with a particular technology, a complete life-cycle assessment would be required. This technique involves tracking components of a system from the materials used to manufacture them, through the manufacturing process, to the point of use, and finally to the disposal or recycling of the product. Unfortunately, such assessments have only been conducted for parts of the system examined here (Blazek et al. 1999; Weidman and Lundberg 2000). Others have addressed related questions but have not treated phone system and Internet electricity using the methods described in this article (Zurkirch and Reichart 2002; Reichart and Hischier 2003; Turk et al. 2003).

These analyses are complex and require extensive data collection. Drawing appropriate system boundaries is also difficult. Until more resources can be brought to bear on this issue, limited analyses like the one described in this article are the best way to address specific claims about network-related electricity use.

More Accurate Estimation of Total Electricity Used by Network Components

There is still much that is not understood about electricity used by various parts of the network, and technology changes quickly. For example, many telecommunications companies plan to move to voice-over IP and away from the standard phone system technologies, which will likely change the electricity intensity associated with delivering telephone services. Bandwidth continues to increase, but new optical switching technologies promise to substantially reduce power used per megabyte transmitted.

Another example is the use of wireless local area networks (e.g., using the 802.11a/b/g protocols) to access the Internet. PDAs that access the Internet using these networks instead of the cellular network would transmit directly to the Internet without going through the POTS, presenting a different scenario from the one assumed here. More careful tracking of equipment types and numbers of units for both existing and new equipment will be required to maintain an understanding of trends in resource use by telephone and network technologies. Data collection on lifetimes, energy use characteristics, and usage patterns of different equipment types is also urgently needed.

More Accurate Estimation of Data Flows Associated with Network Components

To make this analysis more accurate, it would be helpful to understand which parts of the phone network and Internet are used by various wireless devices, so that the boundaries for both data flows and energy use can be drawn more precisely. In addition, having more accurate data on data transmission rates by wireless PDA users is important for improving the accuracy of the calculations. Some e-mail exchanges with heavy users of PDAs in 2002 (Brighthand 2002) indicate that wireless data flows are increasing as the capabilities of PDAs increase. Of course, total data flows are also increasing rapidly, so the fraction of network electricity use associated with current wireless PDAs may or may not be the same as it was in 2000. Further data collection is needed in this area.

More research is also needed into how different kinds of networks treat data flows. For example, switched networks, such as the standard phone system, allocate network bandwidth as described in Coffman and Odlyzko (2001), resulting in network capacities of 1 MB/min. The published data are not clear on how much of total phone system traffic is actually nonvoice data flows and how much is voice traffic. There are also questions about how best to compare nonvoice data flows to those associated with voice calls in switched networks (Coffman and Odlyzko use one approach, but there may be others). In packet-switched networks, voice and data are on a more consistent basis, so the comparison is more straightforward. As the phone system is converted to voice-over IP (i.e., to a packet-switched network), these issues may become less complicated. Fortunately, the standard phone system contributes such a small fraction of the PDA network electricity in 2000 that any uncertainties in how to treat data flows over switched networks will not cause significant errors in our analysis.

Other Types of Wireless Personal Digital Assistants

Since 2000, there has been a proliferation of different types of wireless PDAs, and it is possible that the electricity use associated with these newer networks is somewhat different from the situation considered here. For example, some recent PDAs are able to connect to the Internet using 802.11a/b/g wireless networking at a home or small business. These devices were not widely used in 2000 but have since become much more common. This evaluation does not affect the validity of our year 2000 comparison, but it does open up interesting questions about the trends in electricity use associated with wireless devices, and follow-on work in this area could be quite fruitful.

Conclusions

This article has demonstrated conclusively that a wireless PDA cannot use as much electricity as a refrigerator, even under the most extreme plausible assumptions. In our best-estimate case, total network electricity use associated with a wireless PDA does not exceed 0.1% of the electricity used by a typical existing U.S. refrigerator, and in our upper-limit case it totals less than 1% of an existing refrigerator's electricity use, even with extreme assumptions about PDA usage behavior.

It is inevitable that small errors or differences in interpretation will arise in any complex calculations, but the errors identified here are substantial. Our analysis shows that claims of wireless PDAs using as much electricity as a refrigerator are too high by more than a factor of 1,000. There are those who still cling to the notion that information technology uses vast amounts of electricity, but it is clearly time to put this urban legend to rest.

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