Estimating Energy Use and Greenhouse Gas Emissions of Internet Advertising

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Rapid growth in internet communication in the last decade has augmented and, to some extent, replaced other means of information transfer. This paper attempts to calculate the energy used by "the internet" in transferring a discrete quantity of information and the associated greenhouse gas (GHG) emissions. In this case, we aim to determine the energy used to deliver online advertising to a user. Based on our level of confidence in the information currently available, this analysis is in an early stage that needs significant improvement to become more than an order-of-magnitude estimate.

While others have attempted to quantify the energy used in the United States by delivery of information services via the internet, these analyses have focused principally on end-use equipment (PCs and other devices that users interact with directly) or on servers. In this paper we attempt to calculate an average energy use per gigabyte of data transferred over the internet by quantifying the network energy and data traffic. This estimate includes energy used by network equipment up to either A) the user's terminal in business settings or B) the edge of the user's home. We take a similar approach here to the analysis in Koomey (2004), which explores network energy and data flows associated with wireless personal digital assistants.

This paper calculates the best estimate of network electricity intensity possible using currently available data. It first illustrates the data and methodology used, then presents the results and discusses implications. Finally it describes conclusions and suggests topics for further research.

Table 1. Study Boundaries

Part of the Network	Data Traffic	Energy Use
Internet Backbone	Included	Included
Telephone Network	Included	Included
DSL	Included	Included
Cable (television excluded)	Included	Included
Wireless & Satellite	Included	Included
Fiber & Power Line	Included	Included
Business Servers and Switches	Included	Included
Home Networking Equipment (DSL modems, Cable Set-Top Boxes, Routers, etc.)	Not Included	Not Included
End-Use Devices (PC's, Wireless Handheld Devices, etc.)	Not Included	Not Included

a. Although traffic that passes out of businesses and through the internet is included, business intranet traffic that does not reach the internet is not included here.
b. Cable here includes only data traffic and energy use for non-television uses.

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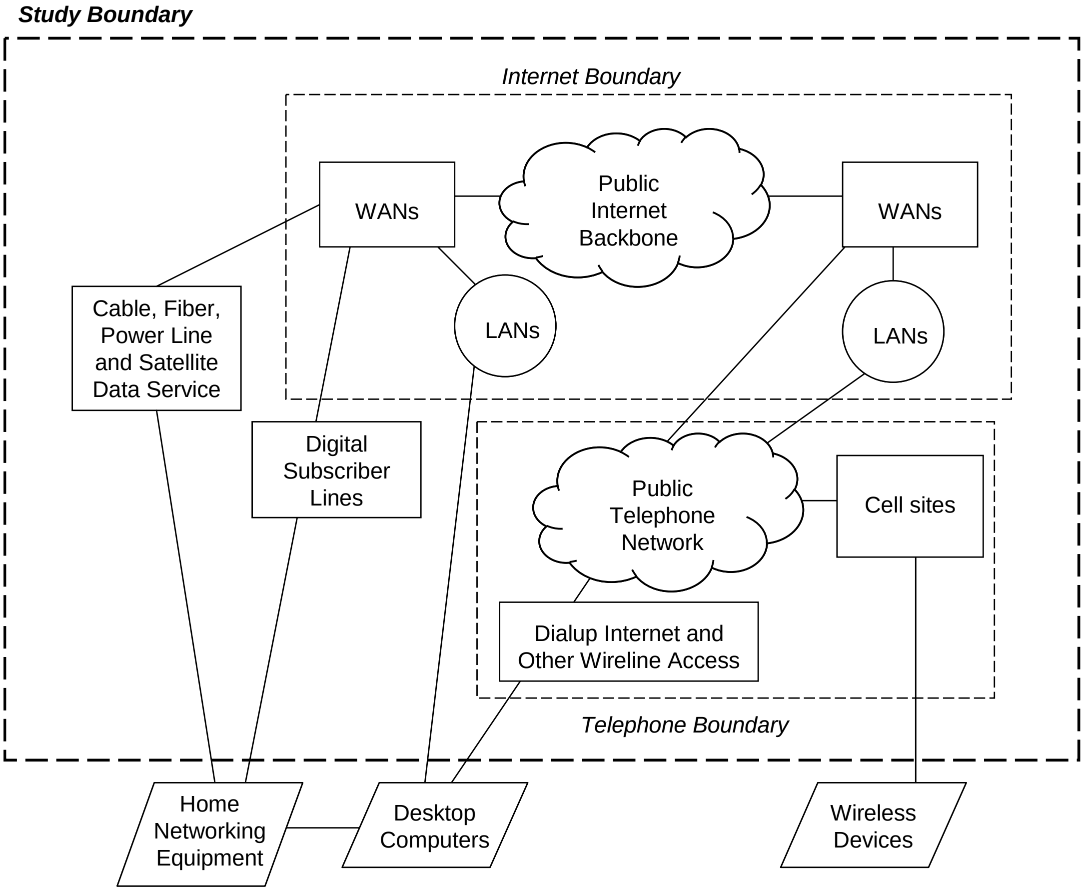

Figure 1: Network Boundaries for This Study – Adapted from Koomey (2004)

Boundaries

Delivery of advertising to the end user requires that the ad flow over numerous machines, and these delivery paths are not always predictable, as shown in Figure 1. There are several paths through which information can travel to the end user, including through the public telephone network and cellular system. This analysis of energy intensity of data transfer includes energy use and data flows for the system components shown in Table 1. This analysis excludes all end-use devices, i.e. personal computers, mobile computing devices, and the like. The analysis does not include modems (DSL and cable modems and routers) (end-use equipment mostly found in homes), but it does include servers and network equipment found inside most businesses. This analysis addresses networks in the United States only.

Although home networking and end-user equipment was beyond the scope of this analysis, the energy use of this equipment should be considered in any complete picture of internet energy usage.

Data and Methodology

In accord with standard practice in end-use energy analysis, we quantify energy required for delivery of the given service. In this case that means quantification of energy used per gigabyte (GB) [3] of data transferred or per advertising impression. We also estimate energy use and emissions associated with a "typical" online advertising campaign. By estimating energy used by the Internet as a whole and the attendant total data transfer, we can estimate the energy used per byte of data transferred over the Internet. The same method of dividing total energy use by total data traffic is used for the telephone system and other access technologies to estimate energy use per byte of data transferred over each access technology. We then weight the access technologies by their respective shares of total traffic to calculate a weighted average energy intensity (kWh/GB) for access technologies as a whole. Each individual packet is assumed to reach an end user by traveling over the internet and over some access technology. The total energy intensity can be calculated by adding the energy intensity for the internet to the weighted average energy intensity for the access technologies.

This method results in the average energy intensity of data transfer over the internet as a whole. While two individual packets may have different energy intensities for their travel (they may travel a different number of hops on the network, and may travel over different access technologies and may travel over more- or less-efficient machines) internet advertising – and most data flows on the internet – can be well-represented by these averages. Even a company with unusually efficient data centers is still subject to the energy used by the intervening equipment to transfer a byte of data to end users.

Two different categories of data traffic and associated energy use are included here. The first is total data traffic across the internet backbone. The second is traffic across the various "access technologies" that data flows over to reach end users, such as the telephone network, the cable network, satellite, cellular, fiber-optic, T1 and other links. An individual data packet might reach a user by passing over the internet backbone then over the telephone network to the user's household. Because PCs and other end-use devices typically use one of these access technologies to receive data that comes from the internet backbone rather than connection directly to the backbone itself, all data flows on the internet eventually pass through one of these access technologies to reach end users. The energy used by these access technologies should be added to the energy used by the internet backbone itself to correctly characterize total energy use in transferring data.

The focus here will be on the year 2006, and because both data flows over the internet and energy used by telecommunications equipment are changing rapidly, the results here should be considered a snapshot only.

Data Flows

We consider data flow over the internet backbone, as represented by the Minnesota Internet Traffic Studies (MINTS) group at the University of Minnesota. MINTS currently lists monthly internet traffic at the end of 2006 as 450-800 Petabytes (PB, 10^{15} bytes) per month. This

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[3] In this paper, we use prefixes consistent with standard metric units when referring to data flows, rather than binary prefixes. Thus, 1MB = 10^6 bytes, not 2^{20} (or 1,048,576) bytes, the standard often used in computing. This consistency allows our results to scale correctly, so 1 kWh/GB is equal to 1 MWh/PB.

estimate comes from confidential data from internet service providers and publicly available logs, primarily those of internet exchanges IXs) and academic networks.

We also consider proprietary data provided by comScore, Inc (Matta, 2007). This data is drawn from comScore's extensive user research pool of over 1.5 million members including US home, work, and school. For each member of the panel comScore monitors the bytes of traffic into and out of the user's computer. This traffic is disaggregated by application, and calibrated via a second control group that allows comScore to scale up its findings to provide an accurate picture of internet usage patterns in the United States. comScore's systems estimates total US data flow at the end of 2006 as 291 PB per month.

That these two data sources would show different numbers is not surprising. The possibility for over- or under-counting exists in the MINTS numbers, as some data may travel over more than one IX, or may not travel through one at all (for instance, traffic that stays within one local carrier). However, at this time it is not clear whether a more accurate measurement of this kind would increase or decrease the total measured traffic volume. The comScore data is well-calibrated to include home, business, and school users, and tracks all traffic in and out of the user's computer, including traffic that may not be captured in by MINTS because it is flowing over some private line network, for instance. However, if there are significant data flows that occur outside of the types of computers tracked in comScore's panel, these may not be represented. This could be because either there are types of end-user computers that account for significant traffic but are underrepresented in comScore's pool, or because there are significant data flows over the network that are not destined for end users' computers. For instance, if there are substantial traffic streams between servers that are not seen by an end user (possibly associated with activities such as edge-of-network caching of video streams, for example), they may not be captured by comScore.

Current estimates of traffic volumes put average download volume at 5 GB per month for DSL users and 10GB per month for homes receiving cable internet service (Odlyzko 2008). Based on a user base of 22.9 million and 28.5 million subscribers respectively in June 2006, download traffic on these lines alone is almost 400 PB/month, which is difficult to reconcile with comScore's total estimated internet data flow of 291 PB/month (Matta 2007).

Data traffic on the conventional telephone system in the United States is estimated from the number of switched access minutes (SAM) tracked by the Federal Communications Commission. The large Incumbent Local Exchange Carriers (ILECs) have filed this information since 1984. These access minutes track the amount of long-distance calling in the US, and they have been falling steadily since 2000, presumably as more long-distance calling services are provided by other (cellular and voice over IP) technologies. By Q3 2006 (the latest period for which these data are available) the usage had dropped to 94 billion access minutes for the quarter, or about 31.3 billion access minutes per month. The FCC suggests (FCC 2003) that Dialed Equipment Minutes (DEM, last collected in 2001) provide the best division between different types of calls. In 2001 the DEM records show that interstate toll calls represented 13% of the total dialed equipment minutes, with intrastate toll and local calling accounting for the rest. Assuming that this ratio is still approximately correct, Total SAM in 2006 are estimated at 2.9 trillion. Because switched access minutes count most calls (except WATS or Wide Area Telephone Service and toll-free) at both ends, this number is divided by two in calculating actual connected minutes. Using the method from Coffman & Odlyzko (1998) we can compute that one minute of voice traffic is equal to 960 kB of data. Therefore, total voice calling traffic is equal to $\left(246 \times 10^{9}\,\text{SAM/month}\right) \times \left(960\,\text{kB/SAM}\right) \div 2 = 118\,\text{PB/month}$

This estimate of total annual traffic on the telephone system includes dial-up internet usage as well as voice traffic. Other data traffic on the telephone network is much more difficult to assess than data flows over the Internet but is thought to represent a very small portion of total traffic on the phone system, as shown in Table 2.

Table 2. Energy Intensity of Network Data Traffic

	comScore Data Flow	MINTS Low Data Flow	MINTS High Data Flow
Internet Backbone			
Internet Traffic, PB/mo	291	450	800
Internet Traffic, PB/yr	3487	5400	9600
Internet Energy Use, TWh/yr	85	85	85
Internet Energy Intensity, kWh/GB	24.3	15.7	8.8
Telephone			
Dialed Traffic, PB/mo	118	118	118
Dialed Traffic, PB/yr	1414	1414	1414
Data Traffic, PB/mo	0.6	0.6	0.6
Data Traffic, PB/yr	7.3	7.3	7.3
Total Phone Traffic, PB/yr	1422	1422	1422
Total Phone Energy Use, TWh/yr	5.1	5.1	5.1
Phone Energy Intensity, kWh/GB	3.6	3.6	3.6

a. All values are for 2006.

b. Telephone system here refers to the switched telephone network. Telephone Data Traffic here refers to high-speed data traffic over telephone lines. Data traffic from dial-up modems is counted under Dialed Traffic.
c. Internet data flow does not include other public data networks or private lines.

d. Energy use values for Internet and phone systems are direct energy use values shown in Table 3 multiplied by a factor of 2 to account for cooling, ventilation, and auxiliary equipment.

We estimate the quantity of traffic carried via digital subscriber lines (DSL), cable, and other non-telephone technologies in Table 4. FCC (2007) records the number of DSL lines at 22.9 million in mid-2006. Little published information exists on the average loading of DSL lines. Odlyzko (2008) claims that at the end of 2007 a plausible average for download traffic on these lines was 5 GB/line per month. Similarly, Odlyzko (2008) puts monthly download volume for cable data customers at 10 GB/line per month at the end of 2007, although this does not include television services provided over the same system. For lack of better data, we assume the same was true at the end of 2006. As Odlyzko (2003) notes, monthly upload volume for high speed lines was equal to approximately half of download volume. However, with the growth of streaming media downloads likely outpacing increases in upload volume, we estimate that average upload volumes for DSL and cable remain largely unchanged since 2003 at 0.5 GB and 1 GB respectively. Thus, total US DSL traffic can be estimated as

$\left(22.9\times10^{6}\ \text{DSL lines}\right)\times\left(6\ \text{GB/mo/line}\right)=126\ \text{PB/month}$ or 1512 PB/year in 2006.

Odlyzko(2003) claims that monthly data traffic volumes for DSL and cable in the year 2003 are 1.5 GB and 3 GB respectively. Hence the method above can be used to estimate DSL data traffic in 2000 as 24 PB/year[4]. The same method and sources can also be used to calculate data traffic over cable lines. Table 4 shows traffic, energy use, and energy intensity for the other access technologies, calculated using the same method.

Energy Use and Greenhouse Gas Emissions

To calculate energy use of internet and telephone system, we began with the estimates in Roth (2002) and EPA (2007a). EPA (2007a) estimates that rates of growth in energy use for network equipment between 2000 and 2006 are almost identical to those for servers. Applying this 14% average annual growth rate from EPA (2007a) for network equipment to the energy use estimates in Roth (2002) yields estimates for network equipment energy use in 2006. These results are summarized in Table 3.

Table 3. Internet and Phone System Direct Energy Use

Equipment Type	2000 electricity use (TWh/year)	2006 electricity use (TWh/year)
Internet *(a)*	19.3	42.3
Servers *(b)*	11.6	24.5
Data Storage *(c)*	1.5	4.4
Hubs *(d)*	1.6	3.5
Routers *(d)*	1.1	2.4
LAN Switches *(d)*	3.3	7.2
WAN Switches *(d)*	0.2	0.3
Telephone System *(a)*	3.8	2.5
Transmission *(e)*	1.8	1.2
Public Phone Network *(e)*	1.0	0.7
Private Branch Exchanges (PBX) *(e)*	1.0	0.7
Total	23.1	44.9

a. these estimates do not include energy use for ventilation, cooling, and auxiliary equipment.

b. From EPA (2007) Includes energy use from all types of servers.

c. Year 2000 value from Roth (2002), year 2006 value scaled by growth factor for Enterprise Storage Devices from EPA (2007).

d. Year 2000 value from Roth (2002, year 2006 value scaled by growth factor for network equipment from EPA (2007).

e. Year 2000 data from Roth (2002), year 2006 value scaled by growth in total phone system data traffic. The estimated decline of energy use in transmission equipment for voice traffic may be offset somewhat by increasing energy use of co-located transmission equipment to carry data traffic.

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[4] Note that the FCC data only began separating out SDSL and high speed traditional wireline services in 2005, so the total for 2000 probably overstates DSL traffic in that year. Also note that because data traffic per DSL line probably grew somewhat between 2000 and 2003, this estimate is likely to overestimate data flow over DSL connections in 2000 and thus underestimate total DSL traffic growth since then

In the absence of better information for 2006, the energy intensity of the phone system (that is, kWh/GB) is here estimated to remain constant between 2000 and 2006. Estimates of the total energy use of the phone system in 2000 are taken directly from Roth (2002). Estimates of the phone system energy intensity are shown in Table 2. These are based on the total phone system data flows in 2000 and 2006 and the total energy use calculated in both years. We include both voice and data flows. Due to simultaneous growth in data traffic and reduction in traditional voice traffic, total traffic on the phone system appears to have declined somewhat since 2000.

Table 4. Customer Internet Access Technology Market Share and Traffic

Access Technology	2006 Number of Lines	2006 Assumed Traffic Per Line, GB/mo	2006 Traffic, PB/yr	Energy Use, TWh/yr	Percent of Lines	Percent of Traffic	Energy Intensity, kWh/GB	Weighted Energy Intensity, kWh/GB
DSL	22,912,448	5.5	1,512	0.25	28%	27.3%	0.17	0.05
Cable	28,513,500	11	3,764	2.72	34%	68.0%	0.72	0.49
Wireless & Satellite	11,872,309	1	142	0.23	14%	2.6%	1.61	0.04
Fiber & Power Line	705,291	11	93	0.07	1%	1.7%	0.77	0.01
Traditional Wireline	610,722	1	7	n/a	1%	0.1%	3.56	0.00
Residential Dial-up	18,277,161	0.06	13	n/a	22%	0.2%	3.56	0.01
Total	82,891,431	-	5,532	-	100%	100.0%	-	0.61

a. The total traffic estimate is an independent bottom-up estimate computed from the data and assumptions in this table. It is not a value chosen specifically to be close to the MINTS low estimate, although it does fall quite close.

b. Number of lines from FCC (2007). Number of Residential Dial-up lines estimated based on number of residential high-speed lines listed in FCC (2007) and percentages of households with broadband and dial-up in U.S. Census Bureau (2008).

c. Traffic per month for DSL and cable from Odlyzko (2008). Others are authors' assumptions. Residential dial-up is based on Odlyzko (2003).

d. Energy use of DSL is based on Roth (2002).

e. Energy use of cable is based on estimates for fiber-to-the-node energy usage at 5 Mbps in Baliga (2008) without the customer-side equipment. This is thought to be a significant overestimate of energy intensity for data transfer because it neglects the use of this system for cable television.

f. Energy use of Wireless and satellite communications is based on estimates for WiMAX energy usage at a speed of 200 kbps in Baliga 2008) without the customer-side equipment.

g. Fiber and Powerline energy use is estimated to be 21.6 W/line from Baliga (2008) assuming a FTTN system operating at 20 Mbps without the customer-side equipment.

h. Energy intensity for traditional wireline and residential dial-up are represented in total phone system energy intensity calculated in Table 2.

Assuming a constant energy intensity, this leads to a slight decrease in total energy use of the phone system to 3.0 TWh/year by the end of 2006. In fact increasing substitution of older switching equipment with newer more efficient equipment may have led to a reduction in energy intensity of the phone system, possibly reducing total phone system energy use further. As long distance carriers increasingly move from fully circuit-switched to packet-switched networks to carry voice traffic inside their systems, they are likely to be gaining efficiency benefits. This trend is independent of the number of customers choosing to use VoIP service, because carriers are replacing an increasing amount of their internal data transmission equipment with packet-switched infrastructure, even where the edge connections are for conventional phone service.

As shown in Table 2, the three different estimates of total internet traffic yield different energy intensities for the internet, although this does not affect estimates for the telephone system or the access technologies. As table 5 shows, all estimates of the internet energy intensity are far higher than the energy intensity of the phone system or other access technologies. For DSL, cable, fiber, powerline, wireless and satellite access, total energy use was calculated by multiplying estimates of energy use per service line from Baliga (2008) and Odlyzko (2003) by the number service lines of each type from FCC (2007). Results for these calculations are shown in Table 4.

Greenhouse gas emissions estimates are taken from the eGRID Database (EPA 2007b), which estimates average US emissions intensity in 2004 (the most recent year for which data was available) as 1363 lbs CO2 equivalent (CO2-e) per MWh. This data source is used because it correctly accounts for emissions from cogeneration units, and the value for GHG intensity is similar to the value that can be derived from the US Energy Information Administration's Electric Power Annual.

Advertising

Based on information from IMC2, we assume here that a "typical" $100,000 media buy involves serving approximately 308 GB of advertising offering 7 million impressions. From this set of assumptions we calculate the advertising energy intensity of 44kB/impression. From here it is possible to calculate energy- and GHG-intensity, and these values are shown in Table 5.

These values suggest that emissions intensity for internet advertising lies in the range of 565-1492 lbs CO_2-e per million impressions, depending primarily on the uncertain total data traffic on the internet. Assuming a carbon offset cost of $10 per metric ton of CO_2 equivalent, this suggests an offset cost of $3-$7 per million impressions. Even considering offset prices ranging up to $30 per metric ton of CO_2 equivalent, the cost of offsets would be only $20 per million impressions, a nominal fee in comparison to the cost of creating and serving the advertising campaign.

Table 5. Total Energy & Emissions

	comScore Data Flow	MINTS Low Data Flow	MINTS High Data Flow
Internet Backbone Energy Intensity, kWh/GB	24.3	15.7	8.8
Access Technologies Weighted Average Energy Intensity, kWh/GB	0.61	0.61	0.61
Total Energy Intensity, kWh/GB	24.9	16.3	9.4
GHG Intensity, lbs $CO_{2\text{-}e}$/MWh	1363	1363	1363
GHG Intensity, lbs $CO_{2\text{-}e}$/GB	33.9	22.2	12.8
Advertising size, kB/impression	44	44	44
Advertising Energy Intensity, kWh/million impressions	1095	716	415
Advertising GHG Intensity, lbs $CO_{2\text{-}e}$/million impressions	1492	976	565

a. All values are for 2006 except GHG intensity, which is 2004 data from EPA (2007b).

Conclusions

The results of this analysis should be used only as a rough guide to estimating emissions of online advertising per impression. Given today's costs for carbon offsets, even the highest emissions levels shown here would lead to negligible cost increases.

Energy intensity of the internet has also declined substantially in recent years. Based on the values calculated in Table 2 for internet energy use and the values for internet data traffic from MINTS, which are available from 1990 forward, we calculate that energy intensity of the internet declined by approximately an order of magnitude from 2000 to 2006. Table 6 illustrates that while energy use approximately doubled in that time period, data traffic grew by more than a factor of 20[5]. This is likely due in part to increasing penetration of more efficient new equipment. The data in this table represent data traffic and energy use for the internet only, because this is the part of the system that is changing the fastest, has the most consistent data set, and frankly is the most interesting.

Table 6. Change in Internet Energy Intensity

	Year 2000	Year 2006	Growth Factor
Internet electricity use (TWh/year)	39	85	2.2
Low MINTS data traffic (PB/year)	240	5400	22.5
High MINTS data traffic (PB/year)	420	9600	22.9
Electricity Intensity (kWh/GB)	92 - 160	9 - 16	0.1

a. Note that these values are for internet only, excluding data flow and energy use of phone and cable networks.

b. Internet data flow does not include other public data networks or private lines.

c. Energy use values for Internet are direct energy use values multiplied by a factor of 2 to account for cooling, ventilation, and auxiliary equipment.

d. The range of 9-16 kWh/GB for energy intensity of the internet in 2006 suggested by the MINTS data is consistent with the estimate of 15 kWh/GB found on pg. 80 of TIAX (2007).

This steeply declining energy intensity suggests that continued migration to the internet of services once provided by other means may reduce overall energy usage. However it is important to remember that end-use devices – the personal computers and other tools for viewing and interacting with all this information – will remain as large contributors to energy use in the information technology sector and represent some of the largest opportunities for increased efficiency (Blazek 1999). It is also important to note that this increasing efficiency in terms of kWh/GB does not come with declining total energy use, because it is largely the result of installing new equipment that uses more energy to deliver higher bandwidth.

Future work

Several opportunities remain to improve this analysis. The most important of these may be work toward acquiring greater certainty about data traffic, starting with reconciling different estimates of total data flows on the internet. In addition, more research into the data flows over other

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[5] Note that this analysis includes uninterruptable power supplies (UPS) in the 2.0 multiplier for cooling, ventilation, and auxiliary equipment, while Koomey (2004) does not. This yields somewhat different values for the year 2000.

public networks and private line networks would hone this analysis. Coffman and Odlyzko (2001) estimate these flows as adding an additional 45% to the internet traffic in 2000, although their role may be diminished if their traffic increase has not matched the twentyfold growth of internet traffic in that time. Energy use of end-use devices should be included in this analysis for a complete picture of the energy use per GB transferred, but for end-use devices it is particularly difficult to correctly allocate energy use among different end-use activities. It will also be important to further disaggregate the data discussed in this paper along a number of dimensions to allow better application of this analysis. Separating out traffic and energy use into source, backbone, and access equipment will allow a company with known server energy usage to calculate the energy used in transmitting its data across unknown backbone and access equipment, for instance.

Refining this assumption by determining the total non-voice data flows over the telephone system would be helpful, but due to the relatively small contribution of the phone system to total energy use of the networks this is not likely to have a large impact. As more data traffic moves to wireless handheld devices served via high-speed cellular networks, it will be important to more closely characterize this element. Koomey (2004) estimates data transfer over the cellular system to be more energy-intensive than either the internet or wireline phone system. An estimate of energy use of the cellular system is also made in Blazek (1999). Overall, determining the energy intensity of the other access technologies (cable, cellular, satellite, fiber optic, etc) would be a fruitful extension of this analysis.

There is still large uncertainty about the energy use of various components of the networks, especially as the technology changes. This may be particularly difficult with technologies such as data service over cable television lines, because there are open questions about how to allocate energy use between different services (data, television, possibly voice calling) emerging in this area. However, even acquiring more accurate measurements of both total number of installed units and average annual energy use per unit is important in improving this analysis. While servers, networking, and data storage have been well characterized by Koomey (2007) and EPA (2007a), incorporation of bottom-up research using similar methods to Roth (2002) would be extremely useful in reducing uncertainty about the equipment in this analysis.

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