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Data Network Equipment Energy Use and Savings Potential in Buildings

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ABSTRACT

Network connectivity has become nearly ubiquitous, and the energy use of the equipment required for this connectivity is growing. Network equipment consists of devices that primarily switch and route Internet Protocol (IP) packets from a source to a destination, and this category specifically excludes edge devices like PCs, servers and other sources and sinks of IP traffic. This paper presents the results of a study of network equipment energy use and includes case studies of networks in a campus, a medium commercial building, and a typical home. The total energy use of network equipment is the product of the stock of equipment in use, the power of each device, and their usage patterns. This information was gathered from market research reports, broadband market penetration studies, field metering, and interviews with network administrators and service providers. We estimate that network equipment in the USA used 18 TWh, or about 1% of building electricity, in 2008 and that consumption is expected to grow at roughly 6% per year to 23 TWh in 2012; world usage in 2008 was 51 TWh. This study shows that office building network switches and residential equipment are the two largest categories of energy use consuming 40% and 30% of the total respectively. We estimate potential energy savings for different scenarios using forecasts of equipment stock and energy use, and savings estimates range from 20% to 50% based on full market penetration of efficient technologies.

Introduction

Network connectivity has become an integral part of daily life, but the aggregate energy use of the network equipment that provides this connectivity is largely unknown. Network equipment consists of the devices whose primary purpose is to transport, route, switch, or process network traffic. The vast majority of these use Ethernet and process Internet Protocol (IP) packets. Devices supporting other physical layers and protocols are in scope as long as the device either can process IP traffic or support Ethernet. This includes switches, routers, firewalls, modems (service provider and customer premises equipment), network security appliances, and wireless access points. Devices with a primary purpose to create, manage, store, or display data are not considered network equipment. These include computers, phones, and displays, even if they have components (e.g. network interface cards) that process IP traffic.

In this paper, we present an estimate of network equipment energy use in the USA and the world broken down by device type and performance. This study includes a categorization of network equipment devices, analysis of the primary factors impacting the power use, and annual energy use estimates and forecasts. We estimated the direct total energy input to network equipment at their power supplies; the estimate does not include the energy used by power or cooling infrastructure. To further inform the study, we evaluated the energy use of a campus local area network (LAN), a commercial building LAN, and residential LAN.

The energy estimates are generated through the product of the stock of equipment in use, the power of the devices, and their usage patterns. We developed stock estimates using market research data, broadband Internet market data, and interviews with network administrators, home network owners, and retail store floor managers. To develop power use estimates, we measured the power consumption of devices under varying conditions and combined this with actual power consumption values (rather than rated power) reported by manufacturers and third party test laboratories. The usage patterns for network equipment were developed through a survey of a campus LAN, discussion with manufacturers, and a review of several home networks.

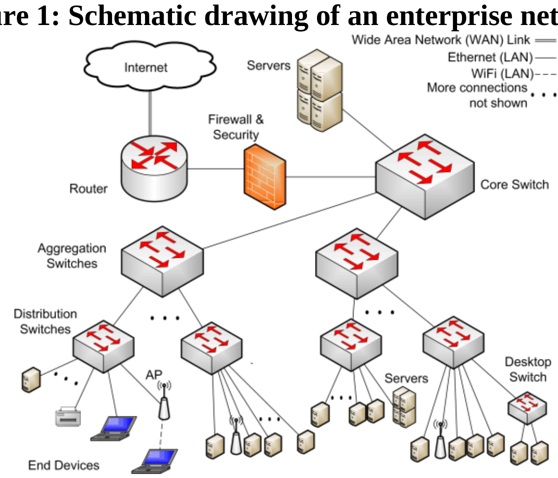
Based on the above approach, we estimate that network equipment in the USA used 18 TWh in 2008 and will grow to 23 TWh in 2012 assuming energy use per unit remains constant (static efficiency). World usage in 2008 was 51 TWh and forecast to grow to 67 TWh in 2012. A look at near term technology to improve energy efficiency suggests that reductions of about 20% are possible when compared to this static efficiency case, and a more aggressive approach shows a potential savings of over 50%.

Background

The electronics end use includes network equipment as well as endpoint devices such as PCs, servers, IP phones, and printers. Network equipment provides data connections between endpoint devices, and the networks are often structured as a redundant tree where the leaves are the endpoint devices and the trunk is called the network core. A graphical representation of the structure (without redundancy) is shown in figure 1.

A key part of understanding network equipment is categorizing and defining equipment types. Switches and routers are used to take data from a source endpoint device and send it to the appropriate endpoint destination. These devices can be standalone units that sit on desktops or in racks, or they can be modular devices configured with line cards selected by the network administrator. Switches and routers are differentiated in that switches have primarily LAN functionality while routers have significant Wide Area Network (WAN) functionality. In an enterprise network, switches are often used in tiers as shown in figure 1. The center of the network is the "core", the next layer (and sometimes layers) is "aggregation", and the last layer closest to the user is "distribution". Although some devices are sold for a particular tier in the network, administrators use switches in different locations depending on the network needs. Note that end devices can be connected at any tier of the network as there is no fundamental difference between switches at any tier. Wireless LAN (WLAN) devices are the access points (APs)

Figure 1: Schematic drawing of an enterprise network



mounted in buildings to provide WiFi access. Networks often have standalone security appliances that inspect network traffic for malicious data, provide user access control, and support virtual private networks (VPNs). A firewall is a common example of a security appliance. Most networks are connected to a service provider network to provide Internet access using a wide area network (WAN) link. The equipment in the service provider office is called customer access equipment, and the equipment used by the customer is called customer premises equipment. This term is most commonly applied to residential and small business networks rather than large enterprise networks.

Network devices have *ports*, physical connection points where cables can be installed. The ports are available in a variety of speeds and with different physical media, and the most common use wired Ethernet, copper wires in twisted-pairs cables, at speeds of 10 megabits per second (Mb/s), 100 Mb/s and 1000 Mb/s. Ports capable of only the first two are often called 10/100 ports, and ports supporting all three are called 10/100/1000 or gigabit Ethernet (GigE) ports. Other common physical connections are fiber optic cable, phone lines, and coaxial cables. Each of these port types has a different impact on the energy use of the device with faster ports typically consuming more power than slower ports. The common case is that each end user of the network is connected to a port on the network equipment, and the network equipment ensures that only traffic for that user is sent out over that port. Some networks use *shared media* where all traffic is sent on a single medium and the end users filter the data. A WiFi network is the most common example of this situation where all users share the same RF space. Cable high-speed Internet and passive optical networks (such as Verizon's FiOS) also use this technique on the WAN side, and power line, phone line, and coaxial cable use this technique in local area networks as well.

Methodology

The total energy use of network equipment is the product of the stock of equipment in use (the total number of ports and/or units actively being used), the power each device uses, and their usage patterns.

Stock

For the stock of enterprise equipment in use, we rely on Infonetics Research sales data and convert annual sales figures to stock-in-use (Machowinski 2010). The data include a world total sales estimate and a combined estimate for the USA and Canada. To remove Canada from the sales numbers, we assume that the products are sold in fractions corresponding to the populations of the two nations. Based on limited interviews with enterprise network administrators, we found that equipment is typically retired after five years of service and that approximately 5% of purchased equipment is held in reserve, retired or otherwise unpowered. We assume 95% of the sales are in operation with a consistent five year lifetime for all enterprise products. Sales information for routers in 2003 and 2004 was unavailable, and the corresponding energy use of products sold in those years is assigned to be zero[1].

[1] For our core estimate year of 2008, only the missing 2004 data are relevant. Our best estimate for 2004 would increase the router total by 15%, and the complete network equipment total by less than 1%.

To estimate the stock of residential equipment[2], we use estimates of the number of users of broadband service provided by the Organization for Economic Cooperation and Development (OECD) (OECD 2007; OECD 2008; OECD 2009a; OECD 2009b) and the Federal Communications Commission (FCC) (FCC 2009) as the primary sources. These data include actual users in a given year and do not include forecasts, but the subscribers are divided by technology type (i.e. DSL, cable, fiber, other). The OECD data are used for worldwide estimates, and we linearly extended the world estimates out to 2012. The US has high broadband penetration rates, and linear growth in all sectors would result in more residential subscribers than households in the USA in 2012. We used the 1996 Census Bureau report that forecasts the number of households in the USA to 2010 (Census 1996), and we linearly extended this forecast to 2012. The total number of residential broadband lines is fixed at 90% of households in 2012; the number of total lines for 2010-2012 is calculated based on estimates of the number of households and market penetration of that year. The fiber to the building sector is assumed to grow linearly at its current rate, and the remaining users are divided among cable, DSL and other at the 2009 market share (excluding fiber services). The FCC also includes data on non-residential lines that use residential class service (and therefore residential class modems), and the number of these lines are scaled to match the residential forecasts based on the fraction of residential to non-residential lines in 2009.

We estimate the network configuration of the DSL, cable and fiber subscribers to estimate equipment in use. We use information gathered from interviewing service providers and retailers on sales and implementation patterns to estimate the fraction of lines that use integrated access devices (IADs) versus those that use modems and WiFi routers. We assume that few users use a modem without a WiFi router and that this number is comparable to those with multiple WiFi routers (or WiFi repeaters). Service providers and device manufacturers provided a 2009 estimate of the market share of modem users and integrated access device (IADs) users. Approximately 80% of DSL users have IADs and 20% use a modem with a WiFi router. For cable Internet users, approximately 80% use standalone modems with a WiFi router and 20% use IADs. One manufacturer believes that nearly all USA DSL users will use IADs in 2012 and half of cable Internet users will use IADs in the same year. Based on this, we linearly scale market penetration from 2007 to 2012. Fiber to the building users do not have a common IAD option, and it is assumed that all fiber users also use a WiFi router. The category of "Other Customer Premises Equipment" covers users of satellite, fixed wireless, and other methods of accessing broadband traffic. Based on interviews with managers in retail stores and power measurements performed by the authors, we conclude that stand-alone wired switches are small contributor to the total residential energy use. A similar estimate for the world was not possible, and we used the same network configuration estimate as the USA case.

Service provider customer access equipment is accounted for using the same broadband market penetration data combined with information from industry. Each user of DSL needs a port on a digital subscriber line access multiplexor (DSLAM), and it is estimated that the ports of a typical DSLAM are less than 80% occupied. We assume that DSL, fiber and cable access equipment is supporting 80% of the maximum number of users although it seems likely that equipment is running at lower capacity on average. If this is true, then more equipment is required to support the same number of users, and the total energy use for access equipment

[2] Some devices in our "Residential equipment" category are also used in small businesses. This primarily includes cable and DSL modems and associated WiFi routers used in cafés, small offices, etc.

could be higher than predicted here. Note that as residential and service provider equipment is estimated with stocks directly rather than from sales, we do not need to estimate average equipment lifetime.

Energy

To estimate annual energy use, we match the network equipment stocks to power consumption and usage estimates. The power estimates are for the entire unit, or per-port, as given by available market or usage data. The typical power used by different devices has been estimated though a number of methods: direct measurement of several products by LBNL, data provided by manufacturers of the devices themselves, results from published reports from third-party test laboratories, and input from device manufacturers. Power levels vary over time; 2008 is our reference year so the stock of equipment in use in 2008 is the basis for our core estimates, and we do not change port or device power use estimates on a year by year basis. Although it has been noted that network equipment is becoming more efficient per unit capacity, we have observed at LBNL that utilization is not increasing as quickly as capacity. Therefore it is difficult to ascertain if equipment is becoming more efficient per unit of data passed over the network, or per end user.

The number and type of ports in the equipment does not alone determine power consumption. Most ports support several link rates (e.g. 10 Mb/s, 100Mb/s and 1000Mb/s), and different link rates consume different power levels. We assume all active links are using the fastest available link rate. A port can be disabled through software, and it can also be enabled but not supporting a link (i.e. the cable is unplugged). These port states result in different power consumption although the base power of a device (before links are added) consumes most of the power in these products. In edge switches, the number of ports supporting links has a more significant impact on power than in core switches.

The amount of data passing through the equipment also impacts power, but the power consumption of switches varies less than 10% between an idle state and a state near capacity. Most switches operate at low levels of throughput utilization making the idle power a reasonable estimate of typical power use. We assume constant power state for network equipment, but the number of ports in use and data throughput both impact power use. We assume the devices are powered on 24 hours a day, 365 days a year at a constant power consumption.

We take as the reference condition for switching products one with no data moving and with only 50% of the ports present actually enabled and supporting a link with the remaining ports active without a link. The power per port is then the total use of the device divided by the number of ports *present*. The ratio for enabled and link-supporting ports to enabled but not supporting a link is derived from a survey of the LBNL campus network which found 40% of ports in use. In this survey, no ports were found to be disabled by administrators.

Annual Network Equipment Energy Use Estimates

Worldwide and USA

Tables 1 and 2 shows world and USA estimates, for network energy use in 2007 and 2008 and forecasts for 2009 through 2012. The estimated power per port or device used is for equipment in use in 2008 and is held constant. The world total for 2008 is 51 TWh (estimated to grow at an annual rate of 9%), and the USA total is 18 TWh (36% of the world total; forecast to grow at 6% annually). In 2008, Buildings in the USA consumed 2750 TWh, and network equipment consumed 0.7% of this total (DOE 2009).

Figure 2 shows a breakdown of energy use by category for the world and the USA. It is notable that the USA and world percentages are very similar suggesting that strategies developed to reduce energy in the USA will be directly applicable to the rest of the world. The largest categories are residential customer premises equipment and switching products which combined use about 70% of the total. Figure 3 shows the switching category in more detail over time for the USA. This chart shows a move to higher speed equipment. Note that the energy use of 10/100 switching equipment is decreasing while 10/100/1000 switching equipment is increasing, and this is the result of a shift in the stock in use from 10/100 to 10/100/1000 devices. The aggregate energy use of the modular devices, common in core networks and data centers, is much lower than that of standalone switches. Although modular devices each consume a lot of power (up to several kW), there are relatively few of them, and the stock is growing slowly. Standalone switches are found in network and telecom closets of businesses of all sizes, and,

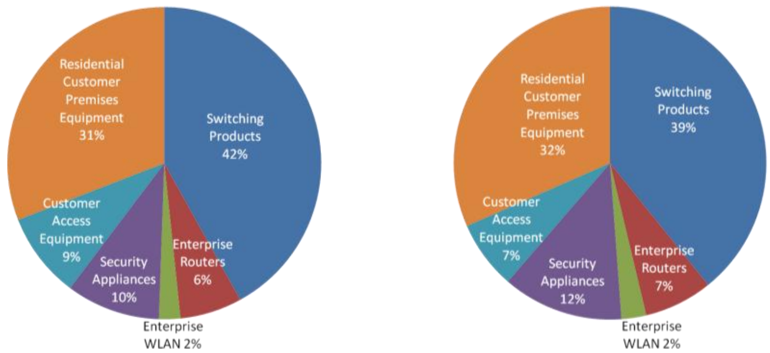
Table 1. Annual worldwide energy use of network equipment broken down by device type (TWh)

Market Segment (Measurement Units)	Power (W) Port/Device	2007	2008	2009	2010	2011	2012
10/100 Standalone Switches (Ports)	1.4	9.2	9.8	9.1	8.9	8.3	7.8
10/100/1000 Standalone Switches (Ports)	2.3	3.9	5.5	6.9	8.4	10.3	12.7
Modular Core Switches & 10G Switches (Ports)	3.6	4.0	4.2	4.1	4.2	4.3	4.7
Total Switching	-	17.1	19.5	20.1	21.5	23.0	25.2
Large Routers (Devices)	400	1.0	1.1	1.1	0.4	0.4	0.4
Small & Medium Routers (Devices)	40	2.0	2.4	2.8	2.3	2.3	2.4
Total Enterprise Routers	-	2.9	3.5	3.9	2.7	2.7	2.9
Enterprise WLAN (Devices)	12	1.0	1.4	1.6	1.8	2.0	2.3
Small & Medium Security Appliances (Devices)	90	3.0	3.5	4.0	4.2	4.3	4.4
Large Security Appliances (Devices)	220	1.5	1.7	2.0	2.1	2.2	2.2
Total Security Appliances	-	4.4	5.2	6.0	6.2	6.4	6.6
Customer Access Equipment	-	4.0	4.6	5.0	5.6	6.1	6.6
Cable Users (Devices)	9.5	4.5	5.1	5.5	6.0	6.5	7.0
DSL Users (Devices)	7.1	8.3	9.3	10.0	10.9	11.7	12.5
Fiber to the Building (Devices)	13	1.4	1.8	2.2	2.6	3.1	3.7
Other	-	0.4	0.4	0.5	0.5	0.6	0.6
Total Residential Customer Premises Equip.	-	14.5	16.6	18.1	20.0	21.9	23.8
Total Energy		44.0	50.8	54.8	57.7	62.1	67.3

Table 2. Annual USA energy use of network equipment broken down by device type (TWh)

Market Segment (Measurement Unit)	*Power (W)* Port/Device	2007	2008	2009	2010	2011	2012
10/100 Standalone Switches (Ports)	1.4	3.3	3.3	3.0	2.7	2.4	2.0
10/100/1000 Standalone Switches (Ports)	2.3	1.6	2.1	2.6	3.1	3.7	4.4
Modular Core Switches & 10G Switches (Ports)	3.6	1.7	1.8	1.8	1.8	1.8	2.0
Total Switching	-	6.5	7.2	7.4	7.6	7.9	8.4
Large Routers (Devices)	400	0.4	0.4	0.5	0.4	0.4	0.4
Small & Medium Routers (Devices)	40	0.7	0.8	1.0	0.7	0.8	0.8
Total Enterprise Routers	-	1.1	1.3	1.4	1.2	1.2	1.3
Enterprise WLAN (Devices)	12	0.4	0.5	0.6	0.6	0.7	0.8
Small & Medium Security Appliances (Devices)	90	1.5	1.6	1.6	1.6	1.6	1.6
Large Security Appliances (Devices)	220	0.7	0.7	0.7	0.8	0.8	0.8
Total Security Appliances	-	2.2	2.3	2.3	2.4	2.4	2.4
Customer Access Equipment	-	1.1	1.3	1.4	1.6	1.8	1.9
Cable Users (Devices)	9.5	2.9	3.2	3.5	3.8	4.1	4.4
DSL Users (Devices)	7.1	1.7	1.9	2.0	2.2	2.4	2.6
Fiber to the Building (Devices)	13	0.1	0.3	0.4	0.6	0.8	1.1
Other	-	0.3	0.3	0.4	0.4	0.5	0.5
Total Residential Customer Premises Equip.	-	5.0	5.7	6.3	7.1	7.9	8.6
Total Energy		16.4	18.2	19.4	20.5	21.9	23.4

Figure 2: Breakdown of Energy Use by Major Product Category in 2008 for the world (left) and the USA (right).



although they consume less power per device, their vast numbers result in larger aggregate consumption.

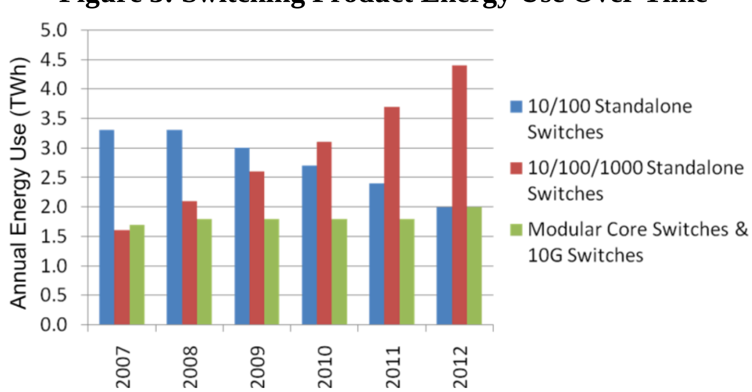
Table 2 also suggests where energy efficiency efforts may have the greatest impact in the USA. The energy use increase from 2007 to 2012 is largest for: cable devices (1.5 TWh), DSL devices (0.9 TWh), fiber to the building devices (1.0 TWh), and 10/100/1000 Ethernet switches (2.8 TWh). The only category expected to use less energy in 2012 than in 2007 is 10/100 switches (-1.3 TWh). These four growing categories account for almost 90% of additional energy consumed in the 2012 forecast compared to the 2007 estimate, and efforts to reduce energy may have the greatest impact if targeted at these growing areas of energy use.

Note that none of our analysis includes energy supplied through Power over Ethernet (PoE) ports such as the energy from a switch power supply that is used to power an IP phone. All "mid-span" products that add PoE power to Ethernet links are also excluded. The reason for this is that the PoE power for end point devices is not in our functional scope; this energy may come out of a network equipment power supply, but it is consumed by end point devices (i.e. IP phones). APs powered by PoE are covered by our estimate because APs are network equipment.

Campus Case Study

The Lawrence Berkeley National Laboratory (LBNL) campus is a diverse campus including building scale scientific instruments, office buildings, laboratories, a supercomputing facility (the National Energy Research Scientific Computing Center, NERSC), and a few small data centers. The campus has 76 buildings situated on 180 acres and has 4000 employees.

Figure 3: Switching Product Energy Use Over Time



The campus LAN, LBLNet, has approximately 450 pieces of managed network equipment and approximately 500 unmanaged desktop switches. Over 200 APs are used to provide WiFi coverage to the campus, and wired coverage is provided by a combination of 170 standalone switches and over 40 modular switches and routers. These managed wired devices combine for a total of 11,000 network ports (on managed equipment), and a typical fraction of these ports active is 40%. Some of the ports on the managed equipment are shared between multiple end devices using a desktop switch, and this is common in large experimental setups or in shared offices. We estimate that the 500 additional switches on the campus add an additional 3500 end use ports to the network. These ports have lower utilization (about 20%). The scale of scientific experiments at LBNL along with a computing facility the size of NERSC would be rare to find in any single campus LAN, and we expect that the consumption of the network will be higher than for a typical corporate campus LAN with a similar number of users.

We obtained an inventory of all of the network equipment in use at LBNL, surveyed ports in use on each piece of equipment, and combined measured and manufacturer reported power consumption to estimate the total annual energy use of the LBNL campus LAN. We estimate that this LAN annually uses 380 MWh, or 94 kWh per employee. The energy use distribution is shown in table 3. Despite the large number of ports added by the small desktop switches, they contribute only 5% of the total energy use. Wireless coverage and security consume relatively small shares of the total as well with 6% and 7% respectively. The vast majority of the use is in managed wired switches (standalone and modular) which consume 80% of the total.

Office Building Case Study

An office building on the LBNL campus is used to show the typical office building consumption. The building surveyed is 90,000 square feet, 5 floors, and houses 450 employees. There are no lab spaces in the building, but there are several network, telecom and/or server closets. This building only has network switches and wireless APs; the associated security and WAN connections are located elsewhere on the campus. Nine APs provide WiFi coverage, and approximately 300 managed ports are available to end devices. There are approximately 70 desktop switches used in the building to provide an additional 500 ports. The total annual energy use for these devices is 12.5 MWh (28 kWh/employee, 140 Wh/ft^2) with 70% of that energy used in managed switches, 22% used in unmanaged, desktop switches, and 8% used by APs. Adding a suitable router with WAN and security capability would add 1.5 MWh bringing the total to 14.0 MWh (31 kWh/employee, 160 Wh/ft^2).

Residential Case Studies

Home networks are extremely simple by comparison to enterprise networks. The typical home network in the USA consists of only one or two network devices. Based on information

Table 3: Annual energy use of network equipment on the LBNL campus

Equipment Type	Annual Energy (MWh)	Percent of Total
Managed Switches and Routers	310	82%
Security Appliances	27	7%
Enterprise Access Points	23	6%
Unmanaged Desktop Switches	20	5%
Total	380	100%

from a service provider and a manufacturer of residential customer premises equipment, the two most common configurations for home networks are as follows:

- A DSL integrated access device (IAD) with a modem, wired switch, and AP in one box
- A cable modem with a separate router with combined wireless and wired capability

About 75% of home networks in the USA are described by these two configurations, and most of the remaining networks use different WAN connections (such as fiber or satellite) or have additional APs or wired switches. The annual energy consumption of a typical DSL integrated access device is 60 kWh, while the typical cable user's network uses 90 kWh/year. The difference is due to the lower energy use of the integrated devices versus two separate devices. In the next few years, service providers expect that cable IADs will become common, and the annual energy use of cable users should approach that of DSL users.

Network Equipment Energy Savings Potential

The energy use estimates do not include any savings through future technology innovation, and this section provides estimates of potential energy savings. Energy use in network equipment is growing as stock increases, network connectivity speeds increase (primarily the change from 10/100 to 10/100/1000 Ethernet) and devices gain more functionality. Three methods of saving energy are considered: Energy Efficient Ethernet, improved power supply efficiency, and improved idle power consumption. These estimates show the magnitude of potential savings and are not a forecast for 2012, as only half of the current equipment stock will be replaced by the end of 2012, and the technologies discussed here are not widely available, if available at all, in current products. In the estimates below, the TWh savings are for the USA.

The move to higher speed is partially addressed by IEEE 802.3az which is better known as Energy Efficiency Ethernet (EEE) (IEEE 2010). Both ends of the link must support EEE to save energy, so broad market adoption should be a priority for policy efforts. Initial estimates suggest that the port physical layer (PHY) can reduce power by 70% at low utilization for gigabit Ethernet (Infineon 2009). The PHY consumes about 1.5W in an assigned and occupied port and 0.8W in an unoccupied port. 70% savings results in 0.8W and 0.3W or approximately 0.6W per typical PHY port compared to 1.1W per port today (with half of the ports assigned and half unused). EEE also includes provisions to save energy at higher layers, but information on the potential savings here is less certain. An additional savings of 0.2W/port (less than 50% of the PHY savings) is a reasonable estimate. Using EEE on all devices supporting gigabit Ethernet results in a savings of 2.8 TWh in 2012 or 12%. Energy will also be saved in the end devices connected to these products nearly doubling the overall savings. The savings assume all devices support EEE. This occurs because if either end of the link does not support EEE, no savings are achieved, so the full potential will take years to realize.

There are currently no specifications for the efficiency of internal power supplies in network equipment (Energy Star and other programs cover external power supplies). A power supply specification similar to that used in the Energy Star computer and server specifications would result in significant savings. There is no comprehensive study of power supply efficiency for network equipment, but computer and server power supplies are a reasonable reference point. A 2006 paper states that typical power supply efficiencies were 60%-70%, with custom designed replacement supplies at 90% (Hoelzle & Weihl 2006). Limited manufacturer data for high end network equipment power supplies suggests that efficiencies are in the 70-80% range (Cisco 2010). If current power supplies in enterprise network equipment are 75% efficient and are replaced with 85% efficient modules, approximately 12% of the energy would be saved. This translates to 2.7 TWh of the total annual energy use in 2012.

The current generation of network equipment consumes almost constant power with respect to varying data throughput, but some researchers believe that power could eventually approach linear scaling of power with throughput in future product generations. The techniques discussed here are commonly lumped into the category of “dynamic power savings”. There are several ways to move towards this goal, and the following is a brief summary.

Currently one chip (integrated circuit or ASIC) is responsible for the operation of several (from 4 to 24) ports, and the chip is not designed to eliminate the power used by one port if a cable is unplugged. We estimate that over 50% of the ports on network equipment are unused, but these ports are not grouped into blocks. This prevents the equipment from shutting off individual ports and saving energy. Redesigning the chips to have individual power domains for each port would enable individual ports to be put into a very low power mode when not in use. The switch fabric (the hardware responsible for moving packets from port to port) is provisioned to move the maximum number of packets at all times. With 50% of the ports unused, this capacity can be reduced by 50% and provide the same level of reliability as the switch provides will all ports connected and the fabric capable of full capacity. Redesigning the switch fabric to allow for changes in capacity (through shutting down various blocks or clock frequency and supply voltage scaling) based on throughput utilization and/or port utilization could achieve 25% savings for switching products (2 TWh in 2012).

The switch fabric and other components could be designed to dynamically scale with throughput in a manner similar to how link throughput (and power) scale with EEE. Because most switches operate at average utilizations of 1%-5%, significant savings are possible. It is estimated that switch power could be cut in half using this method saving approximately 4 TWh in 2012. This method could also be applied to routers, security equipment, and many types of customer premises equipment for total savings of 8.3 TWh per year (36% of the total). Some researchers believe that the savings will be larger, but the estimates here are mid-range.

The three savings techniques are not independent, and they can be adopted together on the same platforms resulting in composite savings. A likely scenario is for both power supply efficiency to be improved and EEE to become widely adopted. This combination would result in savings of 5 TWh (22%). The addition of dynamic power savings would save an additional 7 TWh. The total savings would be 12 TWh or 53% of the total.

Comparisons to Related Work

There have been some attempts to estimate the energy use of the “Internet” or portions thereof. There are no known studies that have specifically attempted to estimate the energy use of all network equipment either in the world or in the USA, but a few reports provide information that is comparable to this work.

Roth, Goldstein & Kleinman (2001) provides an estimate for USA commercial (and industrial) network equipment, but this report does not include residential equipment. The report considers LAN switches, routers, WAN switches, hubs, and some customer access equipment. Stock in use is either estimated by the researchers or pulled from publications and extrapolated to the studies reference year, 2000. The report provides an estimate of 6.4 TWh. A linear extrapolation of our USA estimate to 2000 gives 7.3 TWh for the same equipment categories.

These results compare reasonably well given the large time difference between the studies and the difficulty in rectifying taxonomy misalignment.

Baliga et al. (2009) provide an estimate of network equipment energy use induced by residential Internet traffic . This approach is entirely different from the approach taken in this study, and it therefore provides an interesting comparison point. Baliga et al conclude that 0.5% of the electricity in a typical industrialized nation is for network equipment, and this consumption is dominated by customer premises equipment. To convert the 0.5% value into an estimate for USA energy use, we estimated the average per capita electricity use in the G8, multiplied that by the US population, and then took 0.5% of the total. The total estimated consumption for network equipment is 14 TWh using this method. The electrical energy use and population numbers used to estimate per capita energy use are from 2005, but the US population used for the total is from 2008. The 14 TWh estimate is expected to be low because it does not specifically include enterprise networks, but it is unclear how much this would add. Most traffic that originates or terminates at residential modems does touch commercial networks; therefore some of this energy is included. Our work finds that customer premises equipment is about one third of the total (6 TWh out of 18 TWh) which contrasts with the Baliga's finding that this equipment is over half of the total. Baglia et al. state that the estimate is conservative (an underestimate) of the true total, and we observe that our total is approximately 30% higher.

Future Work

This analysis covers the vast majority of network equipment energy use, but additional work should be undertaken to estimate consumption of other equipment types to confirm that they are small (e.g. repeaters/amplifiers for long-distance transmission).

Telecommunications infrastructure that in the past has been totally or mostly voice traffic has increasing amounts of IP traffic. Thus, some telecom hardware should probably be moved into the network equipment categorization (e.g. mobile phone base stations).

Conclusions

Network equipment consumes about 1% of buildings electricity and is growing at roughly 6% per year in the USA. The great majority of the equipment and energy consumption is in office buildings and residences rather than data centers. A number of techniques for saving energy appear promising, and savings over 10% and up to several tens of percent seem reasonable. Because most enterprise equipment is replaced every 4 to 6 years, energy savings techniques implemented today will see broad market penetration by the middle of the decade.

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