Power Management in Networked Devices

Ken Christensen, University of South Florida
Bruce Nordman and Rich Brown, Lawrence Berkeley National Laboratory

Networks are one of the most significant developments in computing and a hallmark of modern society. However, along with increasing efficiency and productivity, both at home and in the workplace, networks have costs. One cost is the additional energy that electronic devices consume when attached to networks.

Making networked devices "energy aware" could save more than $1 billion per year.

Recent studies indicate that the economic and environmental impact of such energy use is substantial (www.eere.energy.gov/buildings/documents/pdfs/office_telecom-vol1_final.pdf). In 1999, for example, office and network equipment—primarily PCs connected to the Internet—accounted for about 2 percent of US electricity consumption (http://enduse.lbl.gov/Info/LBNL-45917b.pdf). This roughly corresponds to $6 billion in energy costs and the emission of more than 50 million metric tons of carbon dioxide per year.

During the next two decades, energy consumption by digitally networked devices is expected to increase at a faster rate than other types of energy use in buildings. Many such devices will not be PCs but emerging technologies designed for the home rather than the office.

POWER MANAGEMENT

Power management, a standard feature of modern PCs, was primarily developed to increase battery lifetime in laptop PCs, which historically were not network-connected when using battery power. Today, however, many laptops are connected to a network—typically a Wi-Fi network—as are the majority of desktop computers.

The Advanced Configuration and Power Interface (www.acpi.info)—an open industry specification jointly developed by Hewlett-Packard, Intel, Microsoft, Phoenix, and Toshiba—defines standard power management interfaces for modern personal computers. PCs using Microsoft Windows XP and other current operating systems can enter a sleep state that typically decreases overall power consumption by more than 90 percent.

However, low-power sleep modes usually are not compatible with network connectivity. Consequently, in about 95 percent of desktop PCs, power management is disabled, either during machine setup or the first time that the feature interferes with a network application. Display power management is enabled on most PCs, but tens of millions more could readily be enabled.

We estimate that enabling greater use of existing power management features in computer systems would, within a few years, save from 11 to 36 terawatt hours—equal to $0.8 to $2.7 billion—per year. However, achieving these savings without disrupting system performance will require making network devices, applications, and protocols more "energy aware."

DRIVERS OF ENERGY USE

Three key drivers of energy use are *induced consumption* by devices prevented by network connections from entering low-power states, *increasing link data rates* that inherently consume more energy for the network interfaces, and proliferation of *network-connected displays* that actively update and display data when no one is present.

Induced consumption

Most desktop PCs are continuously left fully powered even though there is no user demand for their resources most of the time. This is largely because such resources are increasingly shared and must thus be accessible by remote users and other computers 24/7. Companies customarily back up files and update software at night, while many distributed applications, including server database applications with client front ends, require full-time TCP connections.

A number of existing and emerging protocols, including Universal Plug and Play, require consumer electronic devices to respond to routine "housekeeping" messages, for tasks such as maintaining IP addresses and routing tables, or they risk disappearing from the network. Network protocols designed to provide security or protect content also can increase device on-times.

Existing Ethernet network interface controllers, which can operate on auxiliary power when a PC is in a low-power sleep state, offer one possible solution to the problem of induced consumption. NICs can awaken the main system when they receive a packet defined for this purpose or specific types of ordinary IP packets.

Adding proxy capabilities could enable NICs to directly respond to most low-level protocol messages, triggering a wakeup only when handling a message that requires the main system's resources. This would require a small general-purpose processor for the NIC and new protocols to divide responsibilities between the system and the controller during low-power sleep states. The concept of proxying for power management—adding new hardware and software to a system to reduce overall power consumption—requires further research.

Increasing network link data rates

Link data rates for wired desktop computers connected to the Internet have increased from 10 Mbps to 1 Gbps, which further strains computing system resources. Within a few years, 10-Gbps NICs, which some servers currently use, may be standard in desktop PCs. A 10-Mbps NIC consumes on the order of 1 watt, while a 10-Gbps NIC consumes tens of watts.

Reducing the network link data rate for PCs in low-power states would not affect user productivity. Ethernet autonegotiation mechanisms already exist that allow the link data rate to change. However, new methods are needed to modulate link data rates with traffic levels to scale energy consumption with actual service demand. For example, NICs could be designed to have staged functionality and power states similar to the main PC system. Collectively applying this strategy could potentially save nearly 1 terawatt hour per year in US personal computers alone.

Display proliferation

The rapid transition from CRT to LCD technology, combined with increasingly easy (and often wireless) networking, makes it feasible to utilize multiple displays—each consuming tens of watts—throughout homes and commercial buildings. LCDs are replacing previously unpowered displays in many applications. This large number of displays, hosts, and network interfaces could significantly increase energy consumption.

Researchers must adapt power management efforts to the Internet and the devices that connect to it.

Although power management is enabled in most PC displays, research is needed to develop communication protocols for evolving display usage scenarios and increasingly sophisticated interfaces—among devices as well as users—that facilitate more robust power management. Displays should be asleep or off when not needed; at a minimum, the network processor and interface should be in a low-power state except when explicitly updating display data.

CURRENT RESEARCH

Next-generation wireless devices and sensor networks drive much of the ongoing work on power management. The proliferation of network applications and central data stores has raised concerns about energy use, power infrastructure costs, reliability, and cooling of data centers.

Researchers are developing new network protocols and standards for sharing files, routing packets, and so on to better match server resources to the load in real time. They are also working on methods to reduce heat in processors and lengthen the battery life of the portable devices that use them. In addition, new technologies such as magnetic RAM will enable users to fully power up a PC in hundreds of milliseconds rather than the few seconds required today.

However, to address the increasing energy problems related to networks, developers and designers must explicitly adapt power management efforts to the Internet and the devices that connect to it. Indeed, failure to do so could undo much of the success of Energy Star (www.energystar.gov), a US government labeling program that promotes energy-conscious purchasing by consumers and encourages manufacturers to build more energy-efficient products.

Despite the billions of dollars in potential savings from improved power management, particularly among the growing number of home-networked non-PC devices, little research is going on in this area. Network-related consumption is a new factor as a large consumer of electricity, which helps explain the lack of attention. In addition, industry has many other issues to grapple with that more directly affect sales and profitability. Thus far, the federal government has not filled the void.

The University of South Florida's Green TCP/IP Project (www.csee.usf.edu/~christen/greentcp/main.html) and the Energy End-Use Forecasting group at Lawrence Berkeley National Laboratory in California (http://enduse.lbl.gov/Projects/InfoTech.html) are currently exploring this issue. Maruti Gupta and Suresh Singh at Portland State University also addressed the "greening of the Internet" at the ACM SIGCOMM 2003 conference (www.cs.pdx.edu/~singh/ftp/sigcomm03.pdf).

The IEEE is currently balloting IEEE 1621, a proposed new international standard for power control user interfaces designed to make it easier to enable and use power management in office and consumer electronic devices.

In addition, commercial products that globally control power management settings of desktop PCs are emerging (http://eetd.lbl.gov/Controls/1621). Two companies offering such products are Verdiem in the United States (www.verdiem.com) and 1E in the United Kingdom (www.1e.com).

The evolution of network hardware, software, and applications shows no sign of slowing down. We believe that only an ongoing government-backed research program can realize the full potential of power management in office and consumer equipment. In addition to addressing the research needs outlined here, this would entail uncovering and documenting other major network-related energy problems as well as reviewing major network protocols, both current and in development, to determine how best to incorporate power management.

Government funding of proof-of-concept research could yield a significant return on a very small investment and also help get the attention of industry, which is critical to implementing these solutions. ■

Ken Christensen is an associate professor in the Department of Computer Science and Engineering at the University of South Florida. Contact him at christen@csee.usf.edu.

Bruce Nordman is a principal research associate in the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory. Contact him at bnordman@lbl.gov.

Rich Brown is a scientist in the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory. Contact him at rebrown@lbl.gov.

Editor: Upkar Varshney, Department of CIS, Georgia State University, Atlanta; uvarshney@gsu.edu