Energy Efficient Digital Networks and Data Centers

Technology and Policy Issues

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EDITOR

Energy Science, Engineering and Technology

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ENERGY SCIENCE, ENGINEERING AND TECHNOLOGY

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PREFACE

Digital networks are the foundation of the information services, such as cell phones, e-mail, and the Internet, and are an expanding and indispensable part of our lives. With the wide availability of these networks, many of the devices and equipment we use in buildings increasingly depend on these networks for the functions they perform. Today, networked devices are mostly electronics, but other types of devices are gaining rich communications ability. While the information services provided by these networks are perceived almost universally to provide a net benefit to society, one drawback to these networks is that they increase energy use, both through the direct energy use of the network interfaces and equipment that comprise the network, and in the effect they have on the operating patterns of devices connected to the network. This book investigates a variety of technology and policy issues related to the energy used by digital networks to further the development of several energy efficiency technologies. Several of these technologies have since been introduced to the market, saving energy in California, the United States, and globally.

Chapter 1 – Digital networks are the foundation of the information services, and play an expanding and indispensable role in our lives, via the Internet, email, mobile phones, etc. However, these networks consume energy, both through the direct energy use of the network interfaces and equipment that comprise the network, and in the effect they have on the operating patterns of devices connected to the network. The purpose of this research was to investigate a variety of technology and policy issues related to the energy use caused by digital networks, and to further develop several energy-efficiency technologies targeted at networks.

Improving network energy efficiency often requires addressing not just one device but the network as a whole. For this reason, much of the project research conducted focused on influencing the standard protocols and applications that define the network:

- Working with the Institute of Electrical and Electronic Engineers, this project supported creation of a new technology standard, IEEE 802.3az ("Energy Efficient Ethernet") to enable most Ethernet link technologies to save energy when lightly used, which is most of the time for most interfaces.
- In partnership with the University of South Florida, Intel Corporation, and others, researchers developed the network connectivity proxying concept. The team then worked with the Ecma International standards organization, and its many member companies, to create a technology standard for network proxying.
- Network connections are a significant driver of set-top box energy use, and network presence proxying is an important technology to reduce this energy use.

The project demonstrated that targeted investment in research and technology on networks by the energy efficiency community can result in considerable energy savings. The project findings can be applied to help California meet its energy goals in the coming decades, and also to reduce energy use both nationally and globally.

Chapter 2 – Data centers are a significant and growing component of electricity demand in the United States. This paper presents a bottom up model that can be used to estimate total data center electricity demand within a region as well as the potential electricity savings associated with energy efficiency improvements. The model is applied to estimate 2008 U.S. data center electricity demand and the technical potential for electricity savings associated with major measures for IT devices and infrastructure equipment. Results suggest that 2008 demand was approximately 69 billion kilowatt-hours (1.8% of 2008 total U.S. electricity sales) and that it may be technically feasible to reduce this demand by up to 80% (to 13 billion kilowatt-hours) through aggressive pursuit of energy efficiency measures. Measure-level savings estimates are provided, which shed light on the relative importance of different measures at the national level. Measures applied to servers are found to have the greatest contribution to potential savings.

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Chapter 1

ENERGY EFFICIENT DIGITAL NETWORKS*

Bruce Nordman, Steven Lanzisera and Richard Brown

ABSTRACT

Digital networks are the foundation of the information services, and play an expanding and indispensable role in our lives, via the Internet, email, mobile phones, etc. However, these networks consume energy, both through the direct energy use of the network interfaces and equipment that comprise the network, and in the effect they have on the operating patterns of devices connected to the network. The purpose of this research was to investigate a variety of technology and policy issues related to the energy use caused by digital networks, and to further develop several energy-efficiency technologies targeted at networks.

Improving network energy efficiency often requires addressing not just one device but the network as a whole. For this reason, much of the project research conducted focused on influencing the standard protocols and applications that define the network:

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* This report, LBNL-6254E, was released by the Lawrence Berkeley National Laboratory, Environmental Energy Technologies Division.

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The project demonstrated that targeted investment in research and technology on networks by the energy efficiency community can result in considerable energy savings. The project findings can be applied to help California meet its energy goals in the coming decades, and also to reduce energy use both nationally and globally.

EXECUTIVE SUMMARY

Background

Digital networks are the foundation of the information services, such as cell phones, e-mail, and the Internet, and are an expanding and indispensable part of our lives. With the wide availability of these networks, many of the devices and equipment we use in buildings increasingly depend on these networks for the functions they perform. Today, networked devices are mostly electronics, but other types of devices are gaining rich communications ability. While the information services provided by these networks are perceived almost universally to provide a net benefit to society, one drawback to these networks is that they increase energy use, both through the direct energy use of the network interfaces and equipment that comprise the network, and in the effect they have on the operating patterns of devices connected to the network. Until this project began, there was no significant effort to address the energy consequences of networks in order to save energy through improved technologies and policy.

Purpose

The purpose of this research was to investigate a variety of technology and policy issues related to the energy used by digital networks, and to further the development of several energy-efficiency technologies targeted at networks. Several of these technologies have since been introduced to the market, saving energy in California, the United States, and globally. By collecting and compiling technical information about digital networks, this project sought to help improve policy making from the state through global level. Understanding how these products and technologies affect energy consumption will enable the California Energy Commission and other stakeholders to identify cost-effective energy savings in this area.

Because networks are by their very nature a collection of devices, improving network energy efficiency often requires addressing not just one device but the network as a whole. In many cases this can only be achieved by influencing the standard protocols and applications that define the network. For this reason, much of the research conducted in the project focused on these network standards.

Research Objectives

The project had the following research objectives:

- Advance the potential for Ethernet technology to save energy through changing behavior at times of low data-traffic levels.
- Conduct research on network connectivity proxying, to allow electronic devices to sleep while still connected to the network, with emphasis on how proxying might be standardized and brought into the market.
- Estimate and document the current electricity consumption of network equipment in the United States, and suggest policy measures to reduce it in the future.
- Assess how power consumption is addressed in audio-video network communications technologies such as IEEE 1394.
- Review how connected audio-video devices currently allow their power state to be managed over the network, and develop strategies for how this capability should evolve in the future by minimizing the time devices are on when not needed and enabling maximum energy savings.
- Understand key issues about set-top box energy use, and recommend actions that the Energy Commission may undertake to reduce this.

- Investigate the energy use of hard-wired and builder-installed equipment in new homes, and assess whether energy-intensive equipment types have commercially available products that can significantly reduce energy use.

Research Outcomes

- Working with the Institute of Electrical and Electronic Engineers, this project supported creation of a new technology standard, IEEE 802.3az (also known as "Energy Efficient Ethernet") to enable most Ethernet link technologies to save energy when lightly used, which is most of the time for most interfaces.
- The research team worked with collaborators from the University of South Florida, Intel Corporation, and elsewhere to develop the network connectivity proxying concept. The team then worked with the Ecma International standards organization, and its many member companies, to create a technology standard for network proxying.
- The research team created the first national estimate of network equipment energy use. This research also identified policy directions for California to take in reducing the energy use of network equipment.
- Through careful review of draft Ethernet standards the research team clarified that there was no fundamental conflict between Ethernet Audio/Video Bridging (an emerging networking technology for transmission of audio-video content) and Energy Efficient Ethernet. the project researchers identified several clarifications to assure maximum compatibility between these two technologies.
- The research team created a generic approach to addressing inter-device power control of audio-video products that can be the basis of future technology standards for this industry.
- This research concluded that network connections are a significant driver of set-top box energy use, and identified network presence proxying as an important technology to reduce this energy use.

All of these results enable energy savings nationally and globally, contributing to the California Energy Commission's carbon-reduction goals.

Conclusion

This project showed that networks use significant amounts of California energy, and reduction measures merit attention and investment. The project also showed that network energy use has been increasing and will continue to do so in the near term. Thirdly, the project also demonstrated that targeted investment in research and technology on networks by the energy efficiency community can result in new technology that saves considerable energy. This type of activity will be necessary for California to meet its own goals for energy saving in the coming decades, as well as to save energy on national and global scales.

Recommendations

Networks provide a continuing source of increases in energy use, and this project examined potential reduction strategies. A deep understanding of how network technology affects energy use is essential to choosing how to respond to this challenge. While there is growing interest in the topic nationally and globally, California remains a leader - leveraging our concentration of companies that drive the network industry and electronics generally. The research team recommends:

- Consider potential network issues in new and updated standards for buildings and equipment, including test procedures.
- Identify the most promising near-term technology development options for the Energy Commission to extend California's current track record of working with industry for the benefit of consumers and energy efficiency.
- Demonstrate proxying technology, with an eye to greatly increasing the share of personal computers on the market with proxying capability and to similarly increase proxy use by customers.
- Assess how the networking capabilities of smart appliances and Smart Grid-enabled equipment will affect the energy use of these products, and identify ways to reduce the energy impact of these networking capabilities.

Benefits to California

The short-term, direct benefits to California are as follows:

- As a result of the Energy Efficient Ethernet, energy savings for California should eventually reach tens of millions of dollars per year at little or no cost to consumers.
- Hundreds of millions of dollars per year of electricity in California are used by computers that are fully on, but idle. Proxying has the potential to reduce this significantly at very low cost. An increasing number of devices, besides computers, have sophisticated network connectivity and so could benefit from the technology.
- California now has an accurate and detailed estimate of network equipment energy use, a method to track changes in the total over time, and policy prescriptions to address this growing area of energy use.
- The Ethernet technologies for Ethernet Audio/Video Bridging and Energy Efficient Ethernet can be compatibly implemented, making Ethernet an efficient and viable alternative technology for networking audio and video devices.
- Groundwork has been laid for future standards development to make audio-video devices easier to use and to make power management more transparent and automatic, enabling large savings at virtually no cost.
- California policy-makers now have two identified technologies—Energy Efficient Ethernet and network presence proxying—that can reduce set-top box energy use in the state by 50 percent or more.

SECTION 1: PROJECT GOALS AND OBJECTIVES

This research project explored energy use and potential savings measures for a variety of networking technologies applied to electronic products, including Ethernet, network presence proxying, network equipment, audio-visual bridging, inter-device power control, set-top boxes, and hard-wired and builder-installed equipment. The project also took significant steps toward transforming the markets for digital networks.

Introduction

In a universe of diverse devices, digital networks communicate a vast array of types of information. These networks are analogous to the pavement and intersections of the U.S. road systems, which move many different sizes, capacities, and designs of vehicles. Digital networks instead transmit information, in packets of varying size and complexity. These networks are deeply integrated in our lives, making possible e-mail, cell phones, the Internet, and other information services.

Digital networks are made up of two types of devices, as shown in Figure 1:

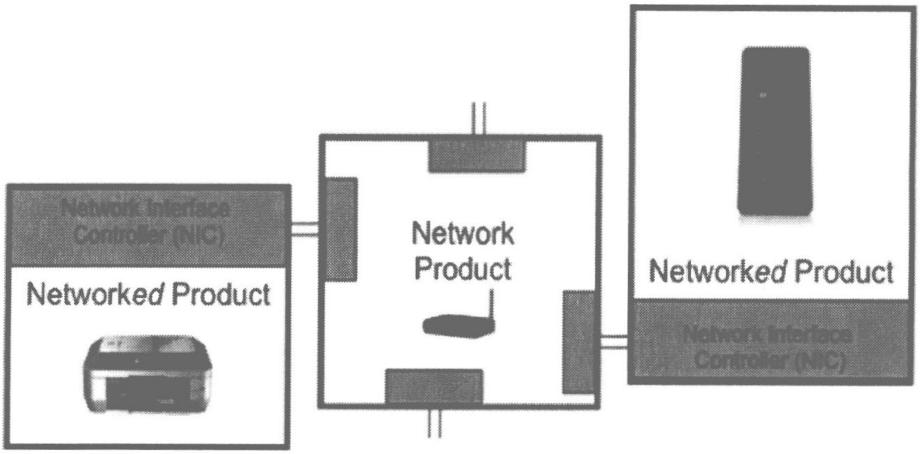
1. Network devices (such as switches, routers, modems, and firewalls) whose primary or only function is to provide network connectivity
2. Network*ed* devices (such as personal computers, set-top boxes, and more recently, televisions), which have some other primary function

All of the devices have network interface controllers (NICs), which move data from the formats used within electronic products to a format used on a network link. A common example of an NIC is the internal personal computer bus (such as a peripheral component interconnect, or PCI) within modern-day computers. A network link is a length of electrical wire, a fiber optic cable, or radio transmissions connecting the two NICs. For data to be transmitted from one device (such as a personal computer) to another device (such as a web server), data packets pass through network switches, routers, and/or servers.

Networks affect energy consumption in several ways:

1. The direct consumption of network interface hardware
2. The direct consumption of network products (e.g., switches and modems)
3. The induced consumption of other products (especially PCs and set-top boxes) by their being in a higher power state than otherwise necessary by virtue of being network-connected.

Most aspects of how a device interacts with a digital network are determined by (1) the other devices on the network, and (2) the industry standards that define behaviors, and therefore are beyond the individual device's control. Low power mode savings for products such as PCs and set-top boxes are possible only with an efficiently operating network. Addressing network standards is the only way to reduce or contain a considerable portion of the energy consumption from electronic devices.



Source: Authors.

Figure 1. Network and Network*ed* Devices.

Background

At the launch of the Energy Efficient Digital Networks project, energy professionals were not experts in key network technologies, and energy savings and efficiency were uncharted territory to most network professionals—there was little intersection between these two fields. In general, little attention was paid to energy analysis and efficiency research when designing digital networks. Design priorities instead focused on performance, reliability, protocol sophistication, security, and hardware cost, while energy was a minor concern or completely absent (Christensen, Gunaratne, et al. 2004). In 2006, no entities whose core mission was energy research were involved in developing the standards responsible for most network energy use.

Mobile devices proved to be the exception, where energy efficiency has long been a design priority because they run on battery power. In 2006, examples included cell phones (to maximize time between charges and to increase service provider revenue and user amenities), personal area networks, and sensor networks. Since that time, mobile devices have expanded to include smart phones, tablets, and miscellaneous Wi-Fi-enabled devices.