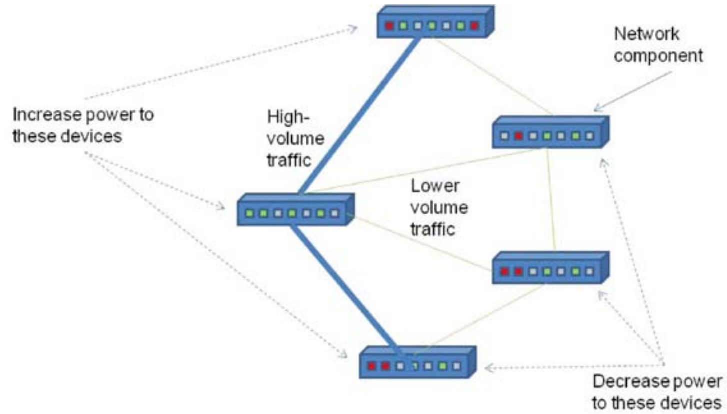
Energy Efficiency of Data Networks through Rate Adaptation

Lowering energy requirements of worldwide network services

This project explored using rate adaptation as a way to synchronize telecommunication network energy demand with real-time network traffic activity.



Adjusting network equipment power to meet changing traffic volume.

Illustration courtesy of the U.S. Department of Energy's Industrial Technologies Program.

Introduction

Most telecommunications infrastructure is designed to handle peak traffic, which requires a far greater throughput capacity than typical traffic. If network equipment can be redesigned so that its energy consumption is proportional to traffic, substantial energy consumption savings are possible.

This project is a concept definition study to develop scientific understanding of rate adaptation in packet-switched network equipment as a way to make energy consumption proportional to actual data traffic. Rate adaptation is a hardware mechanism that controls energy usage by altering processor clock frequency; for example, opportunistically inducing a brief sleep state that uses very little energy. Despite extensive understanding of rate adaptation in the computing world, it has not been extensively explored in the data networking world and its current technological application is immature.

Benefits for Our Industry and Our Nation

Data networking infrastructure is continually growing to meet the nation's communications and business needs, while also improving business productivity and energy efficiency. Telecommunication networking solutions are also incorporated into energy-saving solutions such as smart power grids, road traffic control systems, and teleconferencing. However, such innovations are contributing to this infrastructure's increasing power consumption requirements. Telecommunications infrastructure is not designed to manage power requirements according to real-time network traffic levels. This results in cost inefficiencies, increased wasted energy, and higher release of greenhouse gases. In order to reduce these undesirable technology characteristics, this project identified and tested new approaches to match network equipment power consumption with actual network traffic demands.

Applications in Our Nation's Industry

Most industries, organizations, and private citizens across the globe rely on some form of network communications equipment. Making this equipment more efficient will have a great impact on telecommunications providers and networking services, and a lesser, yet significant, impact on most of the nation's industries and network users. Prominent sectors that will benefit from or be involved in the transition to this technology include the following:

- Digital and voice telecommunications service providers
- Internet service providers
- Organizations with large call centers, data centers, or a high volume of information systems and telecommunications transactions
- Network and telecommunications equipment manufacturers, standards organizations, and resellers

Project Description

Current data networking equipment is designed to be highly available and to handle a wide variety of traffic loads without imposing undue delay. However, energy conservation during low traffic loads has largely been excluded from designs. In order to handle short-term traffic fluctuations, allow for future traffic growth, and provide redundancy in case of equipment failures, most data network links have a maximum capacity that is many times larger than typical traffic. If data networking equipment could be designed so that energy consumption were proportional to actual traffic, rather than independent of it, the energy savings would be substantial.

This project developed a scientific understanding of methods that can enable energy proportionality in packet-switched data networking equipment such as routers and Ethernet switches.

The focus was on algorithms and protocols that can be implemented in software or firmware, appropriately exploiting current and expected hardware capabilities that control energy usage. Such algorithms should be applicable across a broad spectrum of network equipment, irrespective of specific hardware technology or equipment manufacturers. Furthermore, energy savings obtained through algorithmic means are orthogonal and thus added to energy savings obtained by hardware optimization. The expected outcome of the project is scientific documentation of the resulting algorithms and protocols. Some of the algorithms, particularly those specific to individual network elements, can be commercialized immediately and can lead to near-term energy savings, while other algorithms will generate significant impact on a long-term scale.

Barriers

The business model for telecommunications and networking equipment is based on system availability and uptime. This creates incentives for high-performance equipment at the expense of energy efficiency. Although telecommunications service providers are increasingly recognizing the rising energy expenses of this equipment, there is a lag in technology to meet the need. Furthermore, due to the cooperative and heterogeneous nature of network equipment used across the Internet, no single vendor or component can solve the problem. This project addressed these barriers by taking the following actions:

- Identified ways to assure network throughput demand is met with an appropriate measure of electrical power
- Tested the viability of power-saving, rate-adaptation mechanisms with typical internet communications protocols
- Tested methods for the successful application of identified algorithms with multiple federated network elements constrained by an environment of complex traffic routing and scheduling requirements

Pathways

This study was composed of four stages that will inform commercialization activities for energy saving components:

1. Developed a predictive model of packet-switched network equipment energy consumption.
2. Simulated traffic-aware, rate-adaptation algorithms for managing energy consumption within a unit of network equipment.
3. Simulated use of the algorithms with Transmission-Control Protocol (TCP, a commonly used connection protocol of the internet).
4. Simulated synchronized use of the algorithms throughout a global coordination of multiple network elements.

Milestones

- Energy optimization analysis (Completed)
- Energy profiling (Completed)
- TCP performance analysis (Completed)
- Multinode energy optimization analysis (Completed)

Project Partners

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