Until recently, research and development in the area of communications networks has been mainly targeted at functionality and performance. Only for battery-driven devices, such as mobile handsets and wireless sensors, was energy efficiency a significant consideration. This has changed significantly with the massive use of communications in public, professional, and private life coupled with the increasing cost of energy, and with the recognition of the critical need to reduce CO₂ emissions. These economic and ecological drivers have induced a new research area with energy efficiency of general communications networks as the objective. Today we see energy efficiency becoming a pervasive issue for all communication layers and in all technology areas from microelectronics to systems planning and management.

This special issue contains seven tutorial articles by leading researchers in the area of energy-efficient networks. The articles all break new ground in this important new research area. The first article presents a general overview of energy consumption in Internet infrastructure. The next three articles cover different issues of energy efficiency for fixed networks, and the remaining three articles deal with mobile networks. These seven articles are intended to present a wide overview of interrelated problems and solutions.

The first article in this special issue is “Power Consumption and Energy Efficiency in the Internet” by Kerry Hinton, Jayant Baliga, Michael Feng, Robert Ayre, and Rodney S. Tucker. To manage the energy consumption of Internet connected devices, it is important to understand where the energy is consumed. With a focus on fixed networks, the authors identify the components of the network that consume the most energy. Their analysis shows that, in general, access networks currently dominate energy consumption, but that as access speeds grow, the core network routers will begin to dominate. The analysis further shows that for media distribution, the energy consumption of data centers and content distribution networks is dominated by energy for storage of material that is infrequently downloaded and for transport of material that is frequently downloaded. Based on these observations, the authors present a power consumption model for Internet infrastructure that they then use for developing strategies to improve energy efficiency. The next two articles focus on content distribution and access networks — two energy hotspots identified in this first article.

The focus of “Toward Energy Efficient Content Dissemination” by Uichin Lee, Ivica Rimac, Daniel Kilper, and Volker Hilt is on content distribution. A major role of the Internet is to provide content distribution, which includes distributing multimedia content and sharing user-generated data. While optimizing the energy efficiency of data centers is well studied in the literature, understanding the overall energy efficiency of various content dissemination strategies has received comparatively little attention. This article reviews existing content dissemination architectures (including centralized data centers and distributed peer-to-peer) and their energy consumption. The authors conducted simulations showing that a change from a host-oriented to a content-centric networking model where network nodes store and participate in content distribution can substantially reduce energy consumption.

In “Evaluation of ONU Power Saving Modes for GPON” by Björn Skubic and Dave Hood, the focus is on the access network. Access networks in general are designed for low utilization while supporting high peak access rates. As customer premises equipment (CPE) contributes significantly to the overall network power consumption, their low utilization implies a potential for power saving in interfaces and components can be powered down during periods of relative idleness. Two aggressive power saving schemes for passive optical networks (PON) are explored by the authors; they are “cyclic sleep” and “doze mode.” These two schemes have recently been proposed for the upcoming XG-PON standard. The authors show that these schemes reduce the PON CPE energy consumption while still allowing for necessary QoS requirements to be satisfied.

Looking beyond putting CPE to sleep, the fourth article, “Enabling Backbone Networks to Sleep” by Raffaele Bolla, Roberto Bruschi, Antonio Caifrani, and Marco Listanti, explores how backbone networks can use sleep. The authors address the lack of modularity and power management primitives for putting components in sleep mode when not needed. They propose an approach to sleep...
modes in backbone network devices, which they claim can be effectively used to almost halve the energy requirements of the whole telecom core network. The main idea in this article is the notion of being able to periodically reconfigure nodes and links to meet incoming traffic volumes and operational constraints. These operational constraints include reliability, stability, quality of service, and reconvergence times.

In “Energy Efficient Wireless Mesh Infrastructures” by Yahya Al-Hazmi, Karin Anna Hummel, Hermann de Meer, Michela Meo, Harald Meyer, and David Remondo, different approaches to reducing energy consumption in wireless mesh infrastructures (WMIs) are explored. Approaches explored include application layer forward error correction (FEC), turning off network interface cards (NICs), or selecting efficient links, and a relaxed assumption of full coverage. It is shown that energy saving methods can be implemented in a relatively simple reactive way and in a proactive manner (which can have better performance).

In contrast to mesh networks, cellular networks are the topic of “Rethinking Energy-Efficiency Models of Cellular Networks with Embodied Energy” by Iztok Humar, Xiaohu Ge, Lin Xiang, Minho Jo, and Min Chen. The term “embodied energy” denotes the energy consumed for manufacturing and deploying devices and networks. Embodied energy is commonly neglected by research on energy-efficient networks. This article shows that embodied energy contributes significantly to CO2 emissions of communications networks, and that consequently, an assessment of total energy use and savings can be misleading if embodied energy is ignored. This new view leads to practical guidelines for designing energy-efficient cellular access networks.

In the final article of this special issue, Gürkan Gür and Fatih Alagoz focus on a radically new approach to green networks in “Green Wireless Communications via Cognitive Dimension: An Overview.” Wireless cognitive radio (CR) devices adapt to the operating environment via sensing it in order to facilitate efficient and robust communications. CR opens up new control dimensions for green wireless communications, which this article explores. CR offers the promise of an effective trade-off of power consumption and bandwidth usage without reducing throughput.

As these articles show, addressing energy efficiency in networks requires addressing all layers of the network stack, considering both technologies and network management. Approaches should be based on how energy is actually used in networks.

We hope that you enjoy reading this special issue. We certainly enjoyed reading the many excellent submissions. We regret that we could only include seven of the approximately 35 papers submitted.

Biographies

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BRUCE NORDMAN (bnordman@lbl.gov) is a research scientist at Lawrence Berkeley National Laboratory, and has worked there in the Energy Analysis Department for 25 years. He has a M.A. in energy and resources from the University of California, Berkeley. His research covers the intersection of energy use, electronic devices, and networks, ranging from public policy (advising the Energy Star program as well as public organizations in other countries) to technology development. This ranges to topics such as network interfaces and protocols, user interfaces, low-power-made energy use, and building networks. He is active in standards development in IEEE, IETF, Ecma International, and elsewhere. For more information see http://eetd.lbl.gov/ea/nordman.