Preface

INTRODUCTION

Pollution and global warming are important issues that have recently caused many concerns and questions on how to reduce energy and carbon emission successfully. Computing devices, although they only represent currently about 3% of the global energy consumed, now cause about 3% of worldwide CO2 emissions. Thus, their impact on global warming and pollution, while not as significant as the impacts of other contributors, cannot be neglected.

Green computing is a new emerging field that aims to reduce both the power consumption and carbon emissions of computer devices. This new field targets all related computing processes, including designing and manufacturing and the use and disposal of computers, servers, and their associated subsystems in terms of reducing the use of hazardous materials, maximizing energy efficiency, and promoting the recyclability or biodegradability of all computer-related products.

This book consolidates and publishes the current cutting-edge research on techniques, trends, and practical applications in the growing field of Green Computing. It discusses the up-to-date research regarding many aspects of power-aware computing, as the energy consumption relates to components, software creation and production, system levels, networking, and data centers. The book also offers research contributions, constructive debates, and a summary of prior investigations on different case studies related to saving energy and reducing carbon emissions when computing. These topics address different areas, including data centers, networking, communications, software systems, and computer and component design.

This research summary will be a worthy addition to academic and research libraries and indeed a valuable future resource for engineers, researchers, scientists, students, and educators who are working in information technology, computer science, electrical engineering, and mechanical engineering, as well as anyone interested in learning more about Green Computing overall.

The content is offered in four sections: Computing Systems and Clusters, Wireless Networking, Routing and Networking, and Computer and Processor Design and Implementation. Each section includes related chapters that offer basic research and case descriptions, as well as visionary ideas for future applications. The goal is to offer the reader new insights on the issues of power consumption and carbon emissions in computing systems and answer a broad array of questions regarding these topics.

SECTION 1: COMPUTING SYSTEMS AND CLUSTERS

This section discusses Computing Systems and Clusters and contains 5 chapters related to decreasing energy consumption and increasing data throughput via clusters. There are two chapters in particular—one on thermal management issue and a second on Spintronic RAM technology and its use in Normally-off Computers (NOCs).

These two chapters suggest how resilient communities can be created, how an environmentally sound and human-friendly framework for sustainable urbanism can be put in place, and how ICT can be used to encourage more ecologically friendly habits to improve social equity.

In Chapter 1, titled "Improving Energy-Efficiency of Scientific Computing Clusters," Tapio Niemi, Jukka Kommeri, and Ari-Pekka Hameri, describes how operations management principles on scheduling and allocation can be applied to scientific computing clusters to decrease energy consumption and increase throughput. The authors compare the traditional one-job-per-one-processor core scheduling method commonly used in scientific computing to the scheduling method using parallel processing and bottleneck management and those challenges. The authors discuss the impact of increased parallelism on energy consumption by using different test applications that relate to high-energy physics computing. Finally, they demonstrate their methods for both decreasing energy consumption by 60% and increasing throughput to 100% by drawing a comparison with the standard one task per CPU core method.

In Chapter 2, titled "Power Consumption Aware Cluster Resource Management," Simon Kiertscher, Bettina Schnor, and Jörg Zinke, describe an energy-saving technique for clusters that have changing computing demands. First, they offer an overview on energy-saving techniques that can work on the management level. Second, they provide the reader with important standards and specifications related to energy savings, such as ACPI and IPMI. They then describe their energy-saving daemon, CHERUB, which can operate within different Resource Management Systems. Finally, they discuss the results of applying CHERUB's scheduling algorithm.

Chapter 3, titled "Energy-Aware Scheduling for Parallel Applications on Multicore Systems," is written by Jason Mair, Zhiyi Huang, and Haibo Zhang. These authors discuss how energy-aware scheduling techniques can save a significant amount of energy by adopting novel scheduling policies based on better knowledge of performance features collected from the applications. Key techniques for developing an energy-aware scheduler, such as estimation of power usage and performance features per application, are also analyzed and evaluated. The discussion continues with runtime profiling techniques for collecting detailed, application-specific information to be used by the scheduler. The authors focus on the techniques that estimate power usage and performance features, such as speed-up and CPU-intensiveness, which can enable the scheduler to make trade-offs between power consumption and application performance.

In Chapter 4, titled "Dynamic Thermal Management for Multi/Many-Core System," Yang Ge and Qinru Qiu argue that in computing systems, high chip complexity and power consumption will raise chip temperature, reduce chip life, affect chip reliability, and increase cooling costs. They first introduce Dynamic Thermal Management (DTM) techniques that are designed to control chips temperatures and tackle the thermal-related issues and then divide the existing DTM approaches into different categories based on their characteristics. The authors also provide an overview of the working principles and implementation details of specific state-of-the-art DTM techniques and discuss the implementation issues. Finally, they share with the reader their views on the future research directions in this area of computing.

In Chapter 5, "Roles of Non-Volatile Devices in Future Computer System: Normally-Off Computers," authors K. Ando, S. Ikegawa, K. Abe, S. Fujita, and H. Yoda present their overview of the state-of-the-art, emerging magnetic memory *Spintronic RAM* (Spin-RAM) technology that they believe will lead to a new generation of computers or Normally-Off Computers (NOCs). The authors define a NOC and discuss the challenges associated with its design. They then discuss ways in which power consumption in computer systems can be reduced using Spin-RAM technology. Lastly, they share their ideas regarding the current challenges and future research directions in terms of designing this type of computer.

SECTION 2: WIRELESS NETWORKING

In this section, Wireless Networking is covered in 4 separate chapters that discuss cellular networks, smart environments, and the sensor wireless network.

This section opens with Chapter 6, "Energy Efficient Transmission in Cellular Networks," written by Juejia Zhou, Mingju Li, Liu Liu, Xiaoming She, and Lan Chen. It discloses the status of the current research related to energy consumption within the cellular network. First, the authors introduce energy efficient transmission strategies for accessing a network of cellular networks, especially regarding cell selection and power control scopes. As a perspective on future research, this chapter also introduces the roadmap called Smart Radio Resource Management for energy efficient transmission.

In chapter 7, "Green Communications: Realizing Environmentally Friendly, Cost Effective, and Energy Efficient Wireless Systems," Haris I. Volos et al. justify the need for more efficient and environmentally friendly communications by presenting statistics on the energy consumption of today's cellular network infrastructure. "Green Communications" is defined by using different metrics that quantify energy efficiency for all wireless infrastructures. The authors offer a review of key potential techniques to use for improving energy efficiency. Further discussion offers ways of using and managing energy harvested from renewable sources, such as solar and ambient RF signals. The concept of Wireless Distributed Computing is introduced to illustrate how a group of wireless devices can share resources and achieve a set of common goals. Finally, resource allocation is examined in terms of managing the trade-offs involved when allocations simultaneously minimize the carbon footprint and yet still are able to perform necessary communication and computation tasks on mobile devices.

Chapter 8, "Intelligent Systems for Energy Management in Wireless Sensor-Based Smart Environments," authors Blerim Qela and Hussein Mouftah explore and discuss issues related to Smart Environments with an overview of state-of-the-art technological achievements and both the theory and its applications for energy management systems (wireless sensors and intelligent systems). Case studies of real-world applications on the use of "Green Computing" in intelligent systems are also offered. The authors describe their approach, an energy conservation perspective in smart homes and discuss their simulation results. They present examples of large wireless sensor network simulations (impact of topology control on network survivability) and hybrid intelligent techniques for energy efficient solutions. They conclude with a discussion of future research directions for these topics.

Jae-Hyung Lee and Dong-Sung Kim in Chapter 9, "Energy Efficient Routing by Switching-Off Network Interfaces," describe an energy-efficient association technique for Wireless Sensor Networks (WSNs) and how this method can still allow trusted data to be transferred and traffic overloads at specific nodes to be easily prevented. They also demonstrate how using this method can enhance performance of mobile nodes, using data on depth, traffic, and a Received Signal Strength Indicator (RSSI).

SECTION 3: ROUTING AND NETWORKING

Routing and Networking offers the book's third theme. This section contains 4 chapters that cover topics related to routing and networking.

Frédéric Giroire, Dorian Mazauric, and Joanna Moulierac focus on energy consumption in networks in Chapter 10. They discuss optimal solutions to minimize the number of used links while satisfying the bandwidth and quality of service requirements and propose a heuristic algorithm to find routing that minimizes the number of used links, and hence energy consumption, while still satisfying all demands. As precise examples, they apply this algorithm to specific topologies, such as trees, grids, and complete graphs, and calculate the gain in terms of the number of networks. They conclude the chapter by discussing the impact of energy efficient routing on the stretch factor and on fault tolerance.

In Chapter 11, "Energy Optimizations in Broadband Access Networks," M. Guenach, K. Hooghe, M. Timmers, and J. Maes compare two ways for saving energy in access networks: spectral optimization at the physical layer and deployment practices. The chapter focuses on deployment practices and describes how different access network architectures can improve energy consumption when considering both the communication and its supporting functions. Although the chapter focuses on Digital Subscriber Line (DSL) technology, the concepts described can be readily applied to other access technologies, such as optical fibre, cable, or wireless. A case study from the Benelux Company is discussed, and a related innovation in the Swisscom access network demonstrates that in more centralized architectures, further optimizations are also possible.

Hussein T. Mouftah and Burak Kantarci bring more light to the recent research related to energy-efficient design and management of survivable backbone and access networks in "Greening the Survivable Optical Networks: Solutions and Challenges for Backbone and Access." They begin Chapter 12 with a detailed overview of current energy efficiency solutions in telecommunication networks that focus on optical backbone and access networks. The most recent research on energy-efficient survivable provisioning methods and energy-efficient survivable design of the backbone networks is offered. The authors then discuss the existing solutions for energy-efficient survivable PON design and protocol-based solutions with fiber-wireless integration and conclude their discussion by pointing out the still open issues and offering further direction to researchers in the field.

In Chapter 13, "Power Profiling the Internet Core: A Sensitivity Analysis Aruna Prem Bianzino," Anand Raju and Dario Rossi discuss issues regarding accuracy of underlying energy models and their impact on the accuracy of Green Computing results from the scientific community. The authors argue that although most researchers agree on the need for verifiability of such models, they have yet to agree on an effective validation methodology to quantify the reliability of the estimated results. As an example, the authors undertake a careful sensitivity analysis of a power model for the Internet core and show that no matter how carefully the data upon which the power-consumption model relies is chosen and cross verified, the uncertainty of the results remains high. They propose explanations for these results and suggest solutions that can greatly improve the current situation.

SECTION 4: COMPUTER, PROCESSOR DESIGN, AND IMPLEMENTATION

This section includes chapters on Green Computing devices and tools and devices that can decrease computer power consumption.

In Chapter 14, titled "Power Management and Energy Scavenging," Ali Muhtaroglu gives a detailed overview on traditional power management development areas, including architectural power/performance features, low power circuits, power electronics or power delivery, and thermal management system design. Additionally, the chapter throws further light on a recently proposed power management field that has great potential for development, namely, for energy scavenging. As an example, the chapter discusses available energy sources surrounding a computing platform and associated scavenging technologies. The final discussion in the chapter emphasizes a full system approach for effective integration of energy scavengers to practical computing platforms through the use of proper case studies.

Chapter 15, titled "Energy-Aware Switch Design," written by Yukihiro Nakagawa et al., describes the main challenges evident in Ethernet switch designs and energy-aware switch designs, including switch architecture and high-speed IO interfaces. As implementation examples, the authors describe a single-chip switch, Large Scale Integration (LSI) embedded with high-speed IO interfaces, and a 10-Gigabit Ethernet (10GbE) switch blade equipped with the switch LSI. The text compares the performance of this switch blade to the performance of existing commercial 10GbE switch blades.

Chapter 16 is titled "Data-Stream-Driven Computers are Power and Energy Efficient," and here Abdelghani Renbi compares the energy consumption of computers with two architectures: a load/store architecture used in modern computers and a non-instruction, fetch-based system using Field Programmable Gate Array devices (FPGAs). The author discusses the benefits of data-stream-driven computing for better power and energy efficiency. Multiplication is used for the comparison to support the author's statement.

Chapter 17, titled "Temperature-Power Consumption Relationship and Hot-Spot Migration for FPGA-Based Design," is written by Xun Zhang, Pierre Leray, and Jacques Palicot. They bring further light to the relationship between power consumption and electronic device reliability via the heat emission and temperature control in this device. Within this context, this chapter discusses a possible solution for restricting processing component heat emissions in a FPGA-based system (e.g., Cognitive Radio [CR] equipment). It also describes the implementation, on a reconfigurable FPGA-based circuit, of a digital thermal sensor, analyses the applicability of local heat estimations, and empirically defines the temperature-power consumption relationship in a dynamically reconfigurable FPGA platform. Finally, discussion is offered on the use of these sensors to enable actual "hot-spot" migration into CR equipment.

CONCLUSION

Rising pollution levels and worrying changes regarding climate that are arising for the most part from energy processes demand a reduction of an ever-increasing power consumption and environmentally damaging emissions. Computing systems currently represent about 3% of the global energy consumed and cause about 3% of worldwide CO2 emissions. These numbers are expected to increase by 6% by 2020. Developing Green Computing systems will allow significant reductions in these pollution levels.

This book is, thus, a timely contribution to researchers, students, engineers, educators, indeed anyone interested in Green Computing and working in information technology, computer science, electrical engineering, and/or mechanical engineering. It offers a collection of chapters on the current cutting-edge research on techniques, trends, and practical applications in the growing field of Green Computing. It also discusses the up-to-date research on power-aware computing, as energy consumption and carbon emission relates to components, software creation and production, system levels, networking, and data centers. This book is thus a valuable contribution to green computing and, in general, to green energy.

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