Green Communications and Networking

Edited by
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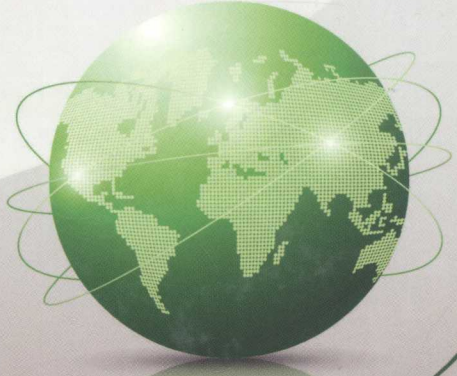

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A Brief Journey through "Green Communications and Networking"

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Introduction

As concerns about climate change, rising fossil fuel prices and energy security increase, companies and governments around the world are committing great efforts to develop new technologies for the green strategies addressing climate change globally and facilitating low greenhouse gas (GHG) development. Currently, the GHG emissions produced by the Information and Communication Technology (ICT) industry alone are said to be equivalent to the GHG emissions of the entire aviation industry. It is estimated that one small computer server generates as much GHG as a sport utility vehicle (SUV). Furthermore, with the increasing demand for higher data rates, the energy consumption for the ICT industry is increasing by 16-20% per year, and the energy costs for mobile network operators can already be as high as half of their annual operating budgets. The role of ICT includes not only the emission reduction and energy savings in ICT products and services, but also enabling low carbon emissions in other industries, such as electric power smart grids. Indeed, networks are crucial technologies for a smart power grid, which monitors, protects and optimizes the operation of its interconnected elements from end to end, with two-way flow of electricity and information to create an automated and distributed energy delivery network.

The contributed articles in this book from the leading experts in this field cover different aspects of modeling, analysis, design, management, deployment, and optimization of algorithms, protocols, and architectures of green

communications and networking. In particular, the topics include energy efficiency, resource management, relay techniques, cross-layer design and optimization, rate adaptation, graph-theoretic approach, router architecture, dynamic scheduling, smart grid communications, demand and response in smart grids, and wireless networks in the smart grid environment. A summary of all of the chapters is provided in the following sections.

PART I: Green Wireless Communications and Networking

As the first chapter of this book, *Chapter 1*, authored by *A. Attar, H. Li and V. C. M. Leung*, introduces a novel solution, named broadband wireless access with fiber-connected massively distributed antennas (BWA-FMDA) to deliver green last-mile access. The advantages of BWA-FMDA architecture are its flexibility of deployment, scalability of coverage from a few meters for indoor access to several kilometers for outdoor communications and superior performance in terms of throughput as well as power efficiency. The focus of this chapter is mainly on power saving capabilities of BWA-FMDA compared with state-of-the-art last mile access solutions. In particular they compare the power consumption model for several last-mile solutions and demonstrate that through integrating optical fibers with wireless access a more power efficient access solution can be envisioned which also enhances the network throughput.

Chapter 2, authored by *X. Zhang and W. Cheng*, develops a Demanding-Based Resources Trading (DBRT) model for green communications. They propose a mechanism to minimize the energy consumption of wireless networks without compromising the quality-of-service (QoS) for users. Applying the DBRT model, they develop a novel scheme – Wireless Networks Resources Trading, which characterizes the trading relationships among different wireless resources for a given number of QoS performance metrics. According to wireless networks resources trading relationships, different wireless resources can be consumed to meet the same set of QoS performance metrics. Therefore, to minimize the energy consumption for given QoS performance metrics, they can trade the other type of wireless networks resources for the energy resources while satisfying the demanded QoS performance metrics. Based on the developed wireless networks resources trading relationships, this chapter derives the optimal energy-bandwidth, energy-time, energy-space and energy-code wireless networks resources trading relationships for green wireless networks. Two example-case studies are also conducted to show how to use the available bandwidth or the acceptable delay bound to achieve the minimum energy consumption while guaranteeing the required QoS performance metrics in wireless networks.

Chapter 3, authored by *Y. Qi, F. Héliot, M. A. Imran and R. Tafazolli*, analyzes the relaying technique at link and system levels from both spectrum efficiency (Se) and energy efficiency (EE) perspectives. A thorough investi-

gation will be provided for a variety of approaches at the relay node (RN) to forward information including amplify-and-forward (AF), decoding-and-forward (DF), compress-and-forward (CF). Advanced relaying schemes, where the conventional relaying schemes are combined in a hybrid manner to adapt to the variations of the channel states, are introduced and investigated. Furthermore, the relaying techniques are combined with retransmission protocols for packet oriented communication systems and a study from spectrum and energy efficiency perspectives is presented. Finally, this chapter also addresses the challenge of designing and positioning RNs in a state-of-the-art wireless cellular system, namely LTE system, coupled with practical power consumption models.

Chapter 4, authored by *T. Zhu, S. Xiao and C. Zhou*, introduces (i) energy-efficient hardware platforms, (ii) energy-efficient MAC, (iii) energy-efficient networking, and (iv) energy-efficient applications. In addition, motivated by the insufficiency of link-layer designs, the authors introduce cross-layer optimization in energy static low-duty-cycle wireless networks. The cross-layer design in energy dynamic low-duty-cycle wireless networks is also studied in this chapter.

Chapter 5, authored by *Z. Zhao, Z. Dou and Y. Shu*, studies energy-efficient rate adaptation in long-distance wireless mesh (LDmesh) networks. The authors propose an efficient probing algorithm to obtain the Frame Delivery Ratio (FDR)-Received Signal Strength Indicator (RSSI) envelope mapping for each bit rate. FDR-RSSI is linear and remains invariant for a period of time so that it can be used to facilitate rate selection. Moreover an energy-efficient rate selection approach is presented to leverage the path loss information based on channel reciprocity. In addition, this chapter provides a technique to detect the distortion of FDR-RSSI that arises from external WiFi interference. The simulation results show that the proposed schemes can improve link throughput efficiently with minimum energy consumption.

PART II: Green Wireline Communications and Networking

Chapter 6, authored by *F. Cuomo, A. Cianfrani and M. Polverini*, studies energy saving in the Internet. The authors present graph-theoretic solutions that can be adopted in an IP network for energy saving purposes. The common idea of these solutions is to reduce the number of links, e.g., router line cards, that are used in the network during the off-peak period. To this aim different properties of the graph that models the network are used. By controlling the impact of the removal of some links on the algebraic connectivity, the proposed scheme derives a list of links that can be switched off. It combines the algebraic connectivity also with the edge betweenness. This latter parameter allows to cut from the network graph links that are crossed only by few paths. The resulting graph algebraic connectivity is then used to control that the

network remains connected and that its connection degree is above a suitable threshold.

Chapter 7, authored by *C. Hu, B. Liu, M. Zhang, B. Zhang and X. Wang*, studies the architectural design of energy-efficient wireline Internet nodes. The authors concentrate on the exploration of power/energy-saving mechanisms through the design of Internet transmission equipment, e.g., routers. By revisiting the characteristics of the Internet behaviors and the modular architecture of routers, this chapter suggests the approach for engineering energy-efficient Internet from three different perspectives and discusses the imposed technical challenges. To address the challenges and seize the energy-saving opportunities, a new conceptual router model/architecture as the guide to design and implement power efficient router, as well as the Internet, is pursued.

Chapter 8, authored by *M. P. Anastasopoulos, A. Tzanakaki and D. Simeonidou*, studies the converged optical network and IT infrastructures suitable to support cloud services. More specifically, the concept of Virtual Infrastructures (VIs), over one or more interconnected Physical Infrastructures (PIs) comprising both network and IT resources, is considered. Taking into account the energy consumption levels associated with the ICT today and the expansion of the Internet, energy efficient infrastructures with reduced CO_2 emissions become critical. To address this, a hybrid energy power supply system for the high energy consuming IT resources is adopted. In this system conventional and renewable energy sources are cooperating to produce the necessary power for the IT equipment to operate and support the required services. The reduction in CO_2 emissions is further increased by applying energy aware planning of VIs over the converged PI. To quantify the benefits of the proposed approach a Mixed Integer Linear Programming model suitable for planning VIs is proposed and developed. This model takes into account multi-period and multi-service considerations over an integrated hybrid-solar powered IT and optical network infrastructure and aims at minimizing the CO_2 emissions of the planned VIs. The modelling results indicate significant reduction of the overall CO_2 emissions that varies between 10-50% for different levels of demand requests.

Chapter 9, authored by *M. J. Neely*, presents a methodology for optimizing time averages in systems with variable length frames. Applications include energy and quality aware task scheduling in smart phones, cost effective energy management at computer servers, and more. The author considers energy-aware control for a computing system with two states: *active* and *idle*. In the active state, the controller chooses to perform a single task using one of multiple task processing modes. The controller then saves energy by choosing an amount of time for the system to be idle. These decisions affect processing time, energy expenditure, and an abstract *attribute vector* that can be used to model other criteria of interest (such as processing quality or distortion). The goal is to optimize time average system performance. The solution methodology of this chapter uses the theory of *optimization for renewal systems*.

PART III: Smart Grid Communications and Networking

Chapter 10, authored by *Z. Li, D. Ishchenko, F. Yang and Y. Ye*, reviews the recent development of utility communication networks, including the advanced metering infrastructure (AMI) and the supervisory control and data acquisition (SCADA). The standardizations of communication protocols in both AMI and SCADA systems are the major focus of this chapter. In addition, some potential grid management applications that are facilitated by the real-time communication mechanism and enable efficient grid operations are also discussed.

Chapter 11, authored by *Q. Dong, L. Yu and W. Song*, surveys the ongoing research through elaborating a representative number of Demand and Response (DR) methods in smart grid and discusses future directions. DR refers to the dynamic demand mechanisms to manage electricity demand in response to supply conditions, and is one of the most important functions of smart grids. DR offers several benefits, including reduction of peak demand, participant financial benefits, integration of renewable resources and provision of ancillary services. This chapter focuses on a classification that is based on the optimization objective. A representative number of DR methods have been stated, which belong to customer profit optimization category operation cost of electric utility reduction category and social welfare maximization category.

Chapter 12, authored by *S. Bu, F. R. Yu and P. X. Liu*, considers not only energy-efficient communications but also the dynamics of the smart grid in designing green wireless cellular networks. Specifically, the dynamic operation of cellular base stations depends on the traffic, real-time electricity price and the pollutant level associated with electricity generation. Coordinated multipoint (CoMP) is used to ensure acceptable service quality in the cells whose base stations have been shut down. The active base stations decide on which retailers to procure electricity from and how much electricity to procure. We formulate the system as a Stackelberg game, which has two levels: a cellular network level and a smart grid level. Simulation results show that the smart grid has significant impacts on green wireless cellular networks, and our proposed scheme can significantly reduce operational expenditure and CO_2 emissions in green wireless cellular networks.

Conclusion

A summary of the contributed chapters has been provided that will be helpful to follow the rest of this book. These chapters essentially feature some of the major advances in the research on green communications and networking for the next generation communications and networking systems. Therefore, the book will be useful to both researchers and practitioners in this area. The readers will find the rich set of references in each chapter particularly valuable.

About the Editors

F. Richard Yu is currently an associate professor in the Department of Systems and Computer Engineering, School of Information Technology, at Carleton University, Ottawa, ON, Canada. He received the Ph.D. degree in electrical engineering from the University of British Columbia, Vancouver, BC, Canada, in 2003. From 2002 to 2004, he was with Ericsson, Lund, Sweden, where he worked on research and development of third-generation cellular networks. From 2005 to 2006, he was with a startup company in California, where he worked on research and development in the areas of advanced wireless communication technologies and new standards. He joined the School of Information Technology and the Department of Systems and Computer Engineering, Carleton University, Ottawa, ON, Canada, in 2007. His research interests include cross-layer design, security, and quality-of-service provisioning in wireless networks.

He received the Carleton Research Achievement Award in 2012, the Ontario Early Researcher Award in 2011, the Excellent Contribution Award at IEEE/IFIP TrustCom 2010, the Leadership Opportunity Fund Award from Canada Foundation of Innovation in 2009 and the Best Paper Awards at IEEE/IFIP TrustCom 2009 and Int'l Conference on Networking 2005. His research interests include cross-layer design, security and QoS provisioning in wireless networks.

Dr. Yu is a senior member of the IEEE. He serves on the editorial boards of several journals, including *IEEE Transactions on Vehicular Technology, IEEE Communications Surveys & Tutorials, ACM/Springer Wireless Networks, EURASIP Journal on Wireless Communications Networking, Ad Hoc & Sensor Wireless Networks, Wiley Journal on Security and Communication Networks*, and *International Journal of Wireless Communications and Networking*, and a guest editor for *IEEE Systems Journal* for the special issue on Smart Grid Communications Systems. He has served on the Technical Program Committee (TPC) of numerous conferences, as the TPC Co-Chair of IEEE CCNC'13, INFOCOM-CCSES'2012, ICC-GCN'2012, VTC'2012S, Globecom'11, INFOCOM-GCN'2011, INFOCOM-CWCN'2010, IEEE IWCMC'2009, VTC'2008F and WiN-ITS'2007, as the Publication Chair of ICST QShine 2010, and the Co-Chair of ICUMT-CWCN'2009.

Xi Zhang received the B.S. and M.S. degrees from Xidian University, Xian, China, the M.S. degree from Lehigh University, Bethlehem, PA, all in electrical engineering and computer science, and the Ph.D. degree in electrical engineering and computer science (electrical engineering systems) from The University of Michigan, Ann Arbor.

He is currently an associate professor and the founding director of the Networking and Information Systems Laboratory, Department of Electrical and Computer Engineering, Texas A&M University, College Station. He was an assistant professor and the founding director of the Division of Computer Systems Engineering, Department of Electrical Engineering and Computer Science, Beijing Information Technology Engineering Institute, China, from 1984 to 1989. He was a research fellow with the School of Electrical Engineering, University of Technology, Sydney, Australia, and the Department of Electrical and Computer Engineering, James Cook University, Australia, under a fellowship from the Chinese National Commission of Education. He was with the Networks and Distributed Systems Research Department, AT&T Bell Laboratories, Murray Hill, NJ, and with AT&T Laboratories Research, Florham Park, NJ. He has published more than 200 research papers in the areas of wireless networks and communications systems, mobile computing, network protocol design and modeling, statistical communications, random signal processing, information theory and control theory and systems.

Dr. Zhang received the U.S. National Science Foundation CAREER Award in 2004 for his research in the areas of mobile wireless and multicast networking and systems. He is an IEEE Communications Society Distinguished Lecturer. He received the Best Paper Awards in the IEEE GLOBECOM 2007, IEEE GLOBECOM 2009, and IEEE WCNC 2010. He also received the TEES Select Young Faculty Award for Excellence in Research Performance from the Dwight Look College of Engineering at Texas A&M University, College Station, in 2006. He is currently serving or has served as an editor for the *IEEE Transactions on Communications*, an editor for the *IEEE Transactions on Wireless Communications*, an associate editor for the *IEEE Transactions on Vehicular Technology*, a guest editor for the *IEEE Journal on Selected Areas in Communications* for the special issue on Broadband Wireless Communications for High Speed Vehicles, a guest editor for the *IEEE Journal on Slected Areas in Communications* for the special issue on Wireless Video Transmissions, an associate editor for the *IEEE Communications Letters*, a guest editor for the *IEEE Communications Magazine* for the special issue on Advances in Cooperative Wireless Networking, a guest editor for the *IEEE Wireless Communications Magazine* for the special issue on Next Generation of CDMA Versus OFDMA for 4G Wireless Applications, an editor for the *John Wiley Journal on Wireless Communications and Mobile Computing*, an editor for the *Journal of Computer Systems, Networking, and Communications*, an associate editor for the *John Wiley Journal on Security and Communications Networks*, an area editor for the *Elsevier Journal on Computer Communications*, and a guest editor for the *John Wiley Journal on Wireless Communications and*

Mobile Computing for the special issue on next generation wireless communications and mobile computing. He has frequently served as a panelist on the U.S. National Science Foundation Research-Proposal Review Panels. He is serving or has served as the Technical Program Committee (TPC) chair for the IEEE GLOBECOM 2011, TPC area chair for the IEEE INFOCOM 2012, general co-chair for INFOCOM 2012 - Workshop on Communications and Control for Sustainable Energy Systems: Green Networking and Smart Grids, TPC co-chair for IEEE ICC 2012 - Workshop on Green Communications and Networking, general co-chair for IEEE INOFOCOM 2011 - Workshop on Green Communications and Networking, TPC co-chair for the IEEE ICDCS 2011 - Workshop on Data Center Performance, Panels/Demos/Posters Chairs for the ACM MobiCom 2011, TPC vice-chair for IEEE INFOCOM 2010, general chair for the ACM QShine 2010, TPC co-chair for IEEE INFOCOM 2009 Mini-Conference, TPC co-chair for IEEE GLOBECOM 2008 - Wireless Communications Symposium, TPC co-chair for the IEEE ICC 2008 - Information and Network Security Symposium, symposium chair for IEEE/ACM International Cross-Layer Optimized Wireless Networks Symposium 2006, 2007, and 2008, respectively, the TPC chair for IEEE/ACM IWCMC 2006, 2007, and 2008, respectively, the demo/poster chair for IEEE INFOCOM 2008, the student travel grants co-chair for IEEE INFOCOM 2007, the general chair for ACM QShine 2010, the panel co-chair for IEEE ICCCN 2007, the poster chair for IEEE/ACM MSWiM 2007 and IEEE QShine 2006, executive committee co-chair for QShine, the publicity chair for IEEE/ACM QShine 2007 and IEEE WirelessCom 2005, and a panelist on the Cross-Layer Optimized Wireless Networks and Multimedia Communications at IEEE ICCCN 2007 and WiFi-Hotspots/WLAN and QoS panel at IEEE QShine 2004. He has served as the TPC member for more than 100 IEEE/ACM conferences, including IEEE INFOCOM, IEEE GLOBECOM, IEEE ICC, IEEE WCNC, IEEE VTC, IEEE/ACM QShine, IEEE WoWMoM, IEEE ICCCN, etc.

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Dr. Leung is a registered professional engineer in the Province of British Columbia, Canada. He is a Fellow of IEEE, a Fellow of the Engineering Institute of Canada, and a Fellow of the Canadian Academy of Engineering. He is a Distinguished Lecturer of the IEEE Communications Society. He is serving on the editorial boards of the *IEEE Transactions on Computers*, *IEEE Wireless Communications Letters, Computer Communications*, the *Journal of Communications and Networks*, as well as several other journals. Previously, he has served on the editorial boards of the *IEEE Journal on Selected Areas in Communications Wireless Communications Series*, the *IEEE Transactions on Wireless Communications* and the *IEEE Transactions on Vehicular Technology*. He has guest-edited several journal special issues, and served on the technical program committee of numerous international conferences. He is a General Co-chair of GCSG Workshop at Infocom 2012, GCN Workshop at ICC 2012, CIT 2012, FutureTech 2012, CSA 2011. He is a TPC Co-chair of the MAC and Cross-layer Design track of IEEE WCNC 2012. He chaired the TPC of the wireless networking and cognitive radio track in IEEE VTC-fall 2008. He was the General Chair of AdhocNets 2010, WC 2010, QShine 2007, and Symposium Chair for Next Generation Mobile Networks in IWCMC 2006-2008. He was a General Co-chair of Chinacom 2011, MobiWorld and GCN Workshops at IEEE Infocom 2011, BodyNets 2010, CWCN Workshop at Infocom 2010, ASIT Workshop at IEEE Globecom 2010, MobiWorld Workshop at IEEE CCNC 2010, IEEE EUC 2009 and ACM MSWiM 2006, and a TPC Vice-chair of IEEE WCNC 2005. He is a recipient of an IEEE Vancouver Section Centennial Award.

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