Guest Editorial
Energy-Efficiency in Optical Networks

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THE increasing concern for environmental and cost issues has made energy efficiency in telecom networks an important theme. According to a recent report [1], today's networks are wasting a lot of energy by consuming 10,000 times more energy than what is really needed. The Internet currently consumes about 0.4% of the total electricity in broadband-enabled countries and is foreseen to quickly reach 1% with the current trend of data transmission rate increase [2]. These numbers have triggered tremendous efforts and collaborations between industry and academia to address this epidemic and challenging problem. Consequently in 2010, Green Touch [3]—a consortium of leading Information and Communications Technology (ICT) industry, academic and non-governmental research experts, was launched aiming to make communications networks 1,000 times more energy-efficient within five years. The joint effort to reach this goal would not only reduce the world's carbon emissions directly contributed by the ICT sector (which is estimated to be around 2%), but also lower the remaining 98% of the carbon emissions contributed by all the other sectors directly and indirectly affected by ICT [3].

Optical communication and networking technologies have been widely applied to both access networks and Internet optical backbone, and further incorporated with other wired and wireless systems in order to enable an end-to-end service-provisioning platform and to support specific application scenarios. This leads to a design paradigm of *integrated optical networks*, which targets better exploration of user experiences, network/carrier economics, and control/management flexibility by way of heterogeneous system integration, end-to-end considerations, and global optimization. Such a design paradigm has driven the emergence of many exciting research topics and applications, such as Long-Reach Passive Optical Networks (LR-PONs), translucent optical networks, Fiber-Wireless (FIWI) integration, and Radio-over-Fiber (RoF).

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Digital Object Identifier 10.1109/JSAC.2014.2335372

To fulfill the requirements of an energy-efficient design, integrated optical networks have been extensively studied in the past few years toward better energy efficiency while maintaining the desired network performance. Such attempts have generally led to new problem definitions and design dimensions that represent a significant departure from the legacy ones. For example, in energy-efficient optical long-haul and access systems, researchers have considered adaptation of transmission rate, coding scheme, and spectrum width so as to reduce the total energy consumption while maintaining delay constraints. Some research has focused on advanced hardware and/or protocol designs that can enable a smart management and sleep schedule over specific energy-consuming modules, in the hope of achieving energy savings without violating service requirements. Some others have followed the direction of novel network/system architecture designs for the integration of two or more networks in hierarchy or in peers, aiming to achieve desired energy efficiency through network-wide resource allocation and global optimization. All these efforts have continued the push for the evolution of cutting-edge technologies and more stringent requirements towards energy-efficient integrated optical networks.

This JSAC special issue is an endeavor to collect and report state-of-the-art research achievements on energy-efficiency in optical networks that have not been sufficiently addressed by the archived research efforts. In response to the Call-For-Papers, a total of 33 submissions were received, and 9 papers were selected for publication after two rounds of reviews. Each of the accepted papers is expected to serve as a representative study for a specific topic under the context of optical network energy-efficiency. In the following, we briefly discuss each accepted paper, in the hope of providing an overview on the technical aspects concerned in this special issue.

The paper "Modelling Energy Consumption in High-Capacity Routers and Switches" by Vishwanath, Hinton, Ayre, and Tucker develops an interesting power model that can help quantify the energy efficiency of Internet equipment at the granularity of per-packet processing, and per-byte store-and-forward packet handling operations. It contributes to a light-weighted and precise mechanism for the network-wide energy footprint measurement with various types of routers and switches under different applications. It offers a method as a valuable framework against which the energy efficiency of current and future generation of load-proportional Internet equipment can be benchmarked.

The paper "Joint Scheduling and Routing for QoS Guaranteed Packet Transmission in Energy Efficient Reconfigurable" by Wu, Fu, Jiang, and Wen, focuses on reconfigurable WDM networks by joint design of traffic scheduling and routing via an interesting traffic matrix decomposition approach. This is achieved by manipulating a tradeoff between the packet delay and the required number of tunable lasers that concerns energy consumption.

The paper "Energy Efficient BaseBand Units (BBU) Placement in a Fixed/Mobile Converged WDM Aggregation Network" by Carapellese, Tornatore, and Pattavina, considers energy efficiency in network infrastructures where both mobile and fixed network traffic are aggregated/backhauled. The authors demonstrate a novel concept of collecting multiple mobile base band units (BBUs) at a common location (or referred to as BBU hoteling) for the formulated BBU placement problem. This allows the separation of a BBU from its cell site and consolidation for better management overhead and energy efficiency.

The paper "A Low-Energy Rate-Adaptive Bit-Interleaved Passive Optical Network" by Suvakovic *et al.* investigates energy consumption of customer premises equipment (CPE) for the new generation of time-division multiplexing (TDM) passive optical networks. The authors consider a low-energy PON and introduce a novel bit-interleaving downstream protocol with complete designs for the network architecture, protocol and some enabling implementation aspects.

The paper "Energy Saving via Dynamic Wavelength Sharing in TWDM-PON" by Wang, H. H. Lee, S. S. Lee, and Mukherjee, considers time- and wavelength-division multiplexed PON (TWDM-PON), which allows wavelength sharing by optical network units (ONUs) in a time-division multiplexing fashion. The authors propose to pack the wavelength usage among the lightly loaded ONUs for saving power consumption and for load balancing. To deal with dynamic traffic, the optimization and algorithm design account for wavelength reassignment and reconfiguration of ONU reception.

On the same topic of next-generation PONs, the paper "Dynamic Power Management at the Access Node and Customer Premises in Point-to-Point and Time-Division Optical Access", by Li, Lee, Chan, Anthapadmanabhan, Dinh, and Vetter, investigates power-saving performance in point-to-point and TDM-PON systems. It is shown that with the suggested power saving mechanisms, the energy-efficiency can be significantly improved without impairing given quality of service (QoS) requirements.

The paper "Renewable Energy-Aware Manycast Overlays" by Schöndienst, Davis, Plante, and Vokkarane, investigates manycasting strategies in the Internet with an optical network backbone for achieving improved energy consumption and associated greenhouse gas emissions for the Drop at Member Node (MA-DMN) overlay algorithm. The basic idea of the proposed approach is to increase the utilization of the network resources that consume less energy while avoiding using those consuming more.

The paper "All Optical Switching Networks with Energy-Efficient Technologies from Components Level to Network Level" by Y. Ji *et al.*, demonstrates their experimental results on a Software Defined Networking (SDN) testbed with all-optical nodes with a multi-level and multi-planar switching architecture. By launching various power-saving mechanisms at the levels of components/modules, node equipment, and network, the paper shows the effectiveness of these power saving mechanisms upon the employed network environment.

The paper "Real-Time Power Control for Dynamic Optical Networks—Algorithms and Experimentation" by B. Birand *et al.* studies monitoring of Quality of Transmission (QoT) performance in all-optical networks by introducing an interesting global optimization algorithm for dynamic control of power level of each wavelength channel. This algorithm enables quick addition and drop of wavelengths without intervening operations of higher level protocols, and is evaluated using an optical testbed with live optical performance monitors.

Acknowledgment

First of all, we would express our sincere appreciation to the reviewers for their invaluable effort in selecting the papers, and all the authors for contributing to this special issue. We thank the JSAC Editorial Board, and in particular Professor Muriel Medard as the Editor-In-Chief and Professor Moshe Zukerman as the mentor, who have greatly helped move the special issue forward. Finally, we thank the Editorial Staff at IEEE for ultimately putting the issue together in its final form.

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Hussein T. Mouftah (S'74–M'76–SM'80–F'90) was with the Department of Electrical and Computer Engineering, Queen's University, Kingston, ON, Canada, from 1979 to 2002, where, prior to his departure, he a Full Professor and the Department Associate Head. In 2002, he joined the School of Information Technology and Engineering (SITE), University of Ottawa, Ottawa, ON, Canada, in 2002 as a Tier 1 Canada Research Chair Professor, where he became a University Distinguished Professor in 2006. He has six years of industrial experience, mainly at Bell Northern Research of Ottawa (currently Nortel Networks). He is the author or coauthor of seven books, 53 book chapters, and more than 1000 technical papers, 12 patents, and 140 industrial reports. Dr. Mouftah is a Fellow of the Canadian Academy of Engineering (2003), the Engineering Institute of Canada (2005), and the Royal Society of Canada: The Academy of Science (2008). He served the IEEE Communication Society (ComSoc) as the Editor-in-Chief of the IEEE Communications Magazine (1995–1997) the Director of Magazines (1998–1999), the Chair of the Awards Committee (2002–2003), the Director of Education (2006–2007), and Member of the Board of Governors (1997–1999 and 2006–2007). He has been a Distinguished Speaker of the IEEE Communications Society (2000–2007). He currently serves IEEE Canada (Region 7) as the Chair of the Awards and Recognition Committee. He is the joint holder of 12 Best Paper and/or Outstanding Paper Awards. He has received numerous prestigious awards, such as the 2008 ORION Leadership Award of Merit, the 2007 Royal Society of Canada Thomas W. Eadie Medal, the 2007–2008 University of Ottawa Award for Excellence in Research, the 2006 IEEE Canada McNaughton Gold Medal, the 2006 EIC Julian Smith Medal, the 2004 IEEE ComSoc Edwin Howard Armstrong Achievement Award, the 2004 George S. Glinski Award for Excellence in Research of the U of O Faculty of Engineering, the 1989 Engineering Medal for Research and Development of the Association of Professional Engineers of Ontario (PEO), and the Ontario Distinguished Researcher Award of the Ontario Innovation Trust.

Chunming Qiao pioneered optical burst switching or OBS, as well as integrated cellular and Wi-Fi technologies, or iCAR around 1999. He has been funded by about a dozen of grants from U.S. National Science Foundation, and a dozen of major IT and telecommunications companies, including Alcatel Research, Bellcore (Telcordia), Cisco, Fujitsu Labs, Google, NEC Labs, and Sprint Advanced Technology Labs. His research has resulted in several patents, and has been featured in*Businessweek*, *Wireless Europe*, and*New Scientists*. He has chaired dozens of international conferences and served as editors for several major IEEE journals/magazines. He has also chaired IEEE ComSoc's Technical Committees on High Speed Networks and Fiber-Wireless Integration (subTC). Prof. Qiao has published hundreds of highly cited papers with an h-index of above 50. He was elevated to an IEEE Fellow for his contributions to optical and wireless network architectures and protocols.

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