GREEN MEDIA: THE FUTURE OF WIRELESS MULTIMEDIA NETWORKS


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By 2015, with the proliferation of wireless multimedia applications and services (e.g., mobile TV, video on demand, online video repositories, immersive video interaction, peer to peer video streaming, and interactive video gaming), and anytime anywhere communication, the number of smartphones and tablets will exceed 6.5 billion as the most common web access devices. Data volumes in wireless multimedia data-intensive applications and mobile web services are projected to increase by a factor of 10 every five years, associated with a 20 percent increase in energy consumption, 80 percent of which is multimedia traffic related. In turn, multimedia energy consumption is rising at 16 percent per year, doubling every six years. It is estimated that energy costs alone account for as much as half of the annual operating expenditure. This has prompted concerted efforts by major operators to drastically reduce carbon emissions by up to 50 percent over the next 10 years. Clearly, there is an urgent need for new disruptive paradigms of green media to bridge the gap between wireless technologies and multimedia applications.

The purpose of this Feature Topic is to solve pressing problems in relation to the increase in energy consumption due to growing multimedia applications. Volume-intensive power-demanding visual traffic over today's network presents new challenges in processing, storage, extraction, and management. The aim is to answer fundamental and practically relevant questions related to design and analysis of: 1) low-power multimedia computing including in-network processing, compression/coding, and signal sensing; 2) low-power multimedia transmission including large-scale hierarchical networks, distributed network storage, and visual sensor networks; 3) low-power multimedia rendering and display including content adaptive display adaptation, environment adaptive presentation, and multimedia display technologies; and 4) low-power multimedia system design including software and hardware architectures, scalable computations, and low-memory implementations. The goal is to cut energy costs arising from excessive sensing, extraction, storage, and signaling. From a network perspective, the aim is to capture realistic behaviors of irregularly dispersed infrastructure, changing socio-spatial configurations, geographic variability due to unplanned deployment of user-installed access points, randomly located nodes, multiclass distributed channel access, and channel propagation characteristics. From a media perspective, the aim is to capture perfect synergy across low-power distributed network computing, embedded vision processing, real-time media data analysis, in-network real-time semantic processing, and camera node management. Against this backdrop, this Feature Topic will address several important interrelated questions for next-generation heterogeneous networks of uninterrupted green media exchange.

We expect that through this Feature Topic, we can foster new solutions to the design, evaluation, and application of wireless green media. This Feature Topic brings together leading researchers and developers from diverse disciplines in system, hardware, software, and application design to the forefront of green radio communications for future sustainable networks. In response to the call for contributions, we

received 27 paper submissions. During the review process, each paper was reviewed by at least three experts in the relevant area through a rigorous two-round review process. Thanks to the courtesy of the Editor-in-Chief of *IEEE Wireless Communications*, Prof. Hsaio-Hwa Chen, nine outstanding papers have been recommended for this Feature Topic, covering various aspects of wireless green multimedia, such as location awareness, information fusion, cross-layer design, in-network processing, storage, scalable video coding, heterogeneous networks, as well as cloud gaming.

In developing new applications for wireless green media, power-efficient and distributed platforms for pervasive sensing, efficient information fusion, quality of experience (QoE) dissemination, and real-time recovery of multimedia information are of paramount importance. The first two articles are related to collaborative in-network data processing and information fusion. In the first article, "A Green Data Transmission Mechanism for Wireless Multimedia Sensor Networks Using Information Fusion" by Zhen-Jiang Zhang *et al.*, a mechanism based on information fusion is proposed for reducing the volume of data being transferred. The mechanism is a trade-off between uploading the results of in-network data processing and uploading all the raw data. In the second article, "Green Multimedia Wireless Sensor Networks: Distributed Intelligent Data Fusion, In-Network Processing and Optimized Resource Management" by Enzo Baccarelli *et al.*, a comprehensive survey on green QoE for multimedia wireless sensor networks (MWSNs) is presented. The most relevant aspects regarding the fusion, storage, transmission, and retrieval of multimedia data from the mobile Internet are discussed. Recent directions on green QoE MWSN are showcased, taking into account data fusion, clustering, and in-network processing.

Location awareness creates new opportunities for distributing the multimedia data over wireless networks, enabling a variety of context-aware applications that require precise location information of network nodes. The third and fourth articles are related to location awareness for wireless green media. The third article, "Location-Aware Visual Radios" by Thang Van Nguyen *et al.*, gives a brief introduction to vision- and radio-based positioning technologies, and then presents illustrative machine learning methodology to successfully integrate vision information and radio time-of-arrival measurements for cooperative localization of ultra-wideband visual radios in harsh indoor environments. In the fourth article, "Toward Green Media Delivery: Location-Aware Opportunities and Approaches" by Hatem Abou-Zeid *et al.*, the authors present opportunities of exploiting location awareness to enable green end-to-end media delivery by proposing new approaches for location-based adaptive video quality planning, in-network caching, content prefetching, and long-term radio resource management. Using location predictions, this article jointly optimizes resource allocation and video quality.

The rapid expansion of wireless multimedia services has led to a tremendous growth of energy consumption in wireless cellular networks. The fifth and sixth articles are related to green multimedia traffic over cellular networks. The fifth article, "Sustainable Communication and Networking in Two-tier Green Cellular Networks" by Zhongming Zheng *et al.*, explores the characteristics and potential of relay node placement and power allocation to maximize both energy sustainability and transmission efficiency in two-tier green cellular networks, where the base stations and relay nodes are powered by sustainable energy sources. The authors show that the network throughput of green cellular networks can be significantly improved and sustained by balancing energy harvesting with energy consumption. In the sixth article, "Energy-Efficient Multimedia Transmissions through Base Station Cooperation over Heterogeneous Cellular Networks Exploiting User Behavior" by Xing Zhang *et al.*, a wireless network is considered where some users in the same geographic area request the same multimedia streams. The authors make the important observation that exploiting user behavior and base station cooperation can potentially reduce power consumption in heterogeneous cellular networks.

In the seventh article, "Cross-Layer Design for Delay and Energy Constrained Multimedia Delivery in Mobile Terminal" by Yun Ye *et al.*, the authors strike the challenging question of how to achieve optimal energy consumption trade-off between computation and communication to maximize the quality-per-energy-unit performance for QoS provisioning. Several power management strategies are introduced for the computation and communication stages in the multimedia delivery process. A cross-layer design for the resource constrained multimedia delivery at the mobile terminal is presented, which looks for optimal system configuration by taking into account resource constraints, optimization goals, and influential performance parameters.

Transmission delay is another important factor that impacts energy consumption, the effect of which is further accentuated when mobile devices such as smartphones and tablets communicate with distant servers in remote locations. In the eighth article, "Approaches of Energy Efficient Transmission Method in Storage-Embedded Wireless Networks" by Shintaro Arai *et al.*, the authors focus on the reduction of energy consumption using the so-called access point equipped with external storage (APES). The proposed methods take into account the relationship between energy consumption and data uploading.

Next-generation mobile devices have to support computation-intensive tasks such as photo-simulations, high-resolution renderings, and interactive animations. In particular, mobile gaming is one of the fastest growing segments of the multimedia entertainment industry, as a computation-intensive application that mandates advanced computer graphics to render realistic and interactive gaming scenes, and smooth actions in gameplay. With this in mind, cloud computing is a promising green solution in terms of manageability of game software, storage, and equipment wastage. The cloud provides computing and storage resources to mobile clients by offloading the heavy lifting to the cloud servers. In the last article, "Cloud Gaming: A Green Solution to Massive Multiplayer Online Games" by Seong-Ping Chuah *et al.*, the authors present a comprehensive overview of cloud gaming in green media, taking into account cloud data centers, graphics rendering, video coding, and network delivery.

BIOGRAPHIES

MAGED ELKASHLAN (maged.elkashlan@qmul.ac.uk) received his Ph.D. degree in electrical engineering from the University of British Columbia, Canada, in 2006. From 2006 to 2007, he was with the Laboratory for Advanced Networking at the University of British Columbia. From 2007 to 2011, he was with the Wireless and Networking Technologies Laboratory at the Commonwealth Scientific and Industrial Research Organization (CSIRO), Australia. He also held an adjunct appointment at the University of Technology Sydney, Australia, between 2008 and 2011. In 2011, he joined the School of Electronic Engineering and Computer Science at Queen Mary, University of London, United Kingdom. His research interests include distributed wireless networks, energy harvesting, cognitive radio, and wireless security. He is currently an Editor of *IEEE Transactions on Wireless Communications*, *IEEE Transactions on Vehicular Technology*, and *IEEE Communications Letters*.

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the Polytechnic Institute of New York University, Brooklyn, in 2011. Since 2011, he has been with Samsung Research America at Dallas, Richardson, Texas, and represents Samsung in ISO/IEC MPEG, participating in high-efficiency video coding (HEVC) and Green MPEG standardization. His current research interests include next-generation video coding standardization, efficient video processing and presentation, and video signal modeling. He has 10+ pending U.S. patents and 25+ publications in journals and conference proceedings in related areas. He is a member of the IEEE Signal Processing Society. He received the 2006 Special Contribution Award from the AVS Workgroup, China, for his contribution in standardizing the AVS Part 7, 2010 Patent Incentive Award from Sharp, and the 2012 and 2013 Individual Award from Samsung Electronics.

YAO WANG [F] is a recognized expert in video coding, networked video applications, medical imaging, and pattern recognition. She joined the faculty of Polytechnic Institute of New York University in 1990 as an assistant professor, and became an associate professor in 1996 and a professor in 2000. She received her Bachelor of Science and Master of Science in electronic engineering from Tsinghua University, Bejing, China in 1983 and 1985, respectively, and a Ph.D. in electrical and computer engineering from the University of California at Santa Barbara in 1990. She authored the well-known textbook *Video Processing and Communications* in addition to writing numerous book chapters and journal articles. She has also served as an Associate Editor of *IEEE Transactions on Multimedia* and *Transations on Circuits and Systems for Video Technology*. Her election to a Fellow of the IEEE was for her contributions to video processing and communications. She is a recipient of the New York City Mayor's Award for Excellence in Science and Technology, Young Investigator Category; co-recipient of the IEEE Communications Society Leonard G. Abraham Prize Paper in the Field of Communications Systems; the Overseas Outstanding Young Investigator Award from the Natural Science Foundation of China; and the Yangtze River Lecture Scholar by the Ministry of Education in China.

MOHSEN GUIZANI [F] is currently a professor and associate vice president for Graduate Studies at Qatar University, Doha. He was chair of the Computer Science Department at Western Michigan University from 2002 to 2006 and chair of the Computer Science Department at the University of West Florida from 1999 to 2002. He also served in academic positions at the University of Missouri-Kansas City, University of Colorado-Boulder, Syracuse University, and Kuwait University. He received his B.S. (with distinction) and M.S. degrees in electrical engineering, and M.S. and Ph.D. degrees in computer engineering in 1984, 1986, 1987, and 1990, respectively, from Syracuse University, New York. His research interests include computer networks, wireless communications and mobile computing, and optical networking. He currently serves on the editorial boards of six technical journals, and is the Founder and Editor-in-Chief of the *Wireless Communications and Mobile Computing* journal published by Wiley (http://www.interscience.wiley.com/jpages/1530-8669/). He was an IEEE Computer Society Distinguished Lecturer from 2003 to 2005. He is a Senior Member of ACM.

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GEORGE K. KARAGIANNIDIS [F] received his University Diploma (five years) and Ph.D degree, both in electrical and computer engineering, from the University of Patras in 1987 and 1999, respectively. From 2000 to 2004, he was a senior researcher at the Institute for Space Applications and Remote Sensing, National Observatory of Athens, Greece. In June 2004, he joined the faculty of Aristotle University of Thessaloniki, Greece, where he is currently a professor and director of the Digital Telecommunications Systems and Networks Laboratory. In January 2014, he joined Khalifa University, UAE, and is currently a professor in the ECE Department and coordinator of the ICT Cluster. His research interests are in the broad area of digital communications systems, with emphasis on communications theory, energy-efficient MIMO and cooperative communications, cognitive radio, smart grid, and optical wireless communications. He is the author or co-author of more than 270 technical papers published in scientific journals and presented at international conferences. He is also the author of the Greek edition of a book on *Telecommunications Systems* and co-author of the book *Advanced Wireless Communications Systems* (Cambridge Publications, 2012). He was a co-recipient of the Best Paper Award of the Wireless Communications Symposium at IEEE ICC '07, Glasgow, United Kingdom, June 2007. He has been a member of Technical Program Committees for several IEEE conferences such as ICC, GLOBECOM, and VTC. In the past he was Editor of Fading Channels and Diversity in *IEEE Transactions on Communications*, a Senior Editor of *IEEE Communications Letters*, and Editor of the *EURASIP Journa of Wireless Communications & Networks*. He was Lead Guest Editor of a Special Issue on Optical Wireless Communications of the *IEEE Journal on Selected Areas in Communications* and Guest Editor of a Special Issue on Large-Scale Multiple Antenna Wireless Systems of the same journal. Since January 2012 he has been Editor-in-Chief of *IEEE Communications Letters*.

TRUNG Q. DUONG received his Ph.D. degree in telecommunications systems at Blekinge Institute of Technology, Sweden, in 2012. He has worked as a visiting scholar at Polytechnic Institute of New York University from December 2009 to January 2010 and Singapore University of Technology and Design from July 2012 to August 2012. In 2013, he joined Queen's University Belfast, United Kingdom, as an assistant professor. He has served as a TPC member for major IEEE conferences, including IEEE ICC, GLOBECOM, WCNC, VTC, and PIMRC. He currently serves as an editor for *IEEE Communications Letters* and *Wiley Transactions on Emerging Telecommunications Technologies*. He has also served as Lead Guest Editor of the Special Issue on Secure Physical Layer Communications of *IET Communications*, Guest Editor of the Special Issue on Cooperative Cognitive Networks of the *EURASIP Journal on Wireless Communications and Networking*, Guest Editor of the Special Issue on Security Challenges and Issues in Cognitive Radio Networks of the *EURASIP Journal on Advances in Signal Processing*, and Guest Editor of the Feature Topic on Millimeter Wave Communications for 5G of IEEE Communications Magazine. His current research interests include emerging technologies in green communications and networking, such as cross-layer design, cooperative communications, cognitive radio networks, and physical layer security.