Editorial: Energy-efficient algorithm and protocol design in sensor networks

Lin Cai*

Department of Electrical and Computer Engineering,
University of Victoria, Victoria, BC, Canada
E-mail: cai@ece.uvic.ca
*Corresponding author

Xuemin (Sherman) Shen

Department of Electrical and Computer Engineering,
University of Waterloo, Waterloo, ON, Canada
E-mail: xshen@bbcr.uwaterloo.ca

Biographical notes: Lin Cai received MASc and PhD degrees (with Outstanding Achievement in Graduate Studies Award) in Electrical and Computer Engineering from the University of Waterloo, Waterloo, Canada, in 2002 and 2005, respectively. Since July 2005, she has been an Assistant Professor in the Department of Electrical and Computer Engineering at the University of Victoria, British Columbia, Canada. Her research interests span several areas in wireless communications and networking, with a focus on network protocol and architecture design supporting emerging multimedia traffic over wireless, mobile, ad hoc and sensor networks. She serves as the Associate Editor for *IEEE Transactions on Vehicular Technology* (2007), *EURASIP Journal on Wireless Communications and Networking* (2006) and the *International Journal of Sensor Networks* (2006).

Xuemin (Sherman) Shen is a Professor and University Research Chair in the Department of Electrical and Computer Engineering, University of Waterloo, Canada. His research focuses on mobility and resource management in wireless networks, UWB wireless communications and wireless security. He is a co-author of three books, and has published more than 300 papers and book chapters. Dr. Shen serves as the TPC Chair for *IEEE Globecom'07*, General Co-Chair for *Chinacom'07* and *QShine'06*. He also serves as a Founding Area Editor for *IEEE Transactions on Wireless Communications*; Editor-in-Chief for *Peer-to-Peer Networking and Application*; Associate Editor for *IEEE Transactions on Vehicular Technology*. He received the Excellent Graduate Supervision Award in 2006, the Outstanding Performance Award in 2004 from the University of Waterloo and the Premier's Research Excellence Award (PREA) in 2003 from the Province of Ontario, Canada. Dr. Shen is a registered Professional Engineer of Ontario, Canada.

The advance of digital electronics, embedded systems and wireless communications makes the Wireless Sensor Networks (WSNs) with promising potential to support many commercial and military applications. Sensor networks usually operate under a set of unique constraints and requirements, which spark numerous research interests in almost every layer of the network protocol stack. Sensor nodes are usually battery-powered and energy-constrained. Energy efficiency is of primary importance for the operational lifetime of a sensor network. Novel signal processing technologies, network architectures, protocols, algorithms and applications are needed to improve the energy efficiency and prolong the lifetime of sensor nodes and sensor networks. There are extensive efforts in the areas of energy-conscious network topology control, collaborative signal processing, Media Access Control (MAC), variable topology multi-hop routing, flow and error control, and domain-specific application design. Novel cross-layer approaches have also been emerging to address the energy efficiency issue through a combined solution via efforts from different layers. This special issue consists of 12 papers addressing recent cutting edge research and state-of-the-art technology of energy-efficient algorithm and protocol design in sensor networks. It is timely and valuable for the future design, implementation and experiments.

The first four papers promote novel, energy-efficient signal processing technologies. In the first paper, Nguyen and Le-Ngoc propose a combined cooperative coding and hybrid-

Automatic Repeat reQuest (ARQ) scheme suitable for power-efficient transmission in wireless sensor networks. By exploiting cooperative coding in multiple-node WSNs to provide spatial diversity in addition to time diversity offered by ARQ, the proposed scheme can support high-performance transmission at low power consumption. In the second paper, a novel correlated data gathering scheme for energy- and bandwidth-limited WSNs is proposed by Hua and Chen, based on distributed source coding. The proposed scheme takes the advantage of the known parity bits at the decoder when the data is encoded by distributed source coding. In the third paper, Ferrari, Pagliari and Martalò introduce the concept of sensor SNR profile, and they consider four possible profiles (linear, quadratic, cubic and hyperbolic) as representative of a large number of realistic scenarios. They also demonstrate the impact of the sensor SNR profile, and present an asymptotic performance analysis, deriving a simple expression for the limiting probability of decision errors. In the fourth paper, Lecuire, Duran-Faundez and Krommenacker propose an open-loop image transmission scheme and a closed-loop one. Both schemes are based on wavelet image transform and semi-reliable transmission to achieve energy conservation. It is shown that up to 70% and 90% reductions in energy consumption with the open-loop and closed-loop schemes, respectively, compared with a non-energy-aware one.

Data aggregation and topology control are particularly important for the lifetime of WSNs. In the fifth paper, Cheng and Yin propose a new algorithm, Balanced Aggregation Tree (BAT), for data gathering tree construction. They also demonstrate how to determine the value of the control parameter for the best energy efficiency of a given network. The sixth paper by Zou, Nikolaidis and Harms introduces the concept of flow loss multiplier to express the impact of data aggregation over correlated data. The application can set the flow loss multiplier to reflect its specific knowledge of correlation to reduce the traffic load and thus conserve energy. Then, flow-based routing is used to spread the load to increase network lifetime. The seventh paper investigates efficient topology control protocols for 3-D sensor networks. Wang, Li and Dahlberg extend several 2-D geometric topologies to 3-D case, and propose some new 3-D Yao-based topologies for sensor networks. They also prove several important properties (e.g. bounded degree and constant power stretch factor) for them in 3-D space.

With multi-hop wireless communications and energy constraints, WSNs pose new challenges on routing and relay selection, which are the main focus of the following four papers. In the eighth paper, the Clustering-Based Expanding-Ring Routing Protocol (CBERRP) is proposed by Jia, Zhao and Ma, which mainly focuses on the network layer while integrating factors from other layers to gain the preferred performance in terms of network lifetime, power consumption and throughput. In the ninth paper, Lian and Naik present a novel Skip Face Routing (SFR) protocol to reduce the face traversal cost incurred in the existing face routing algorithms. In SFR, a set of sufficient conditions is specified, so that each node can determine if it can skip some intermediate nodes during face traversing based solely on the neighbour information of the node, and therefore the total number of transmissions is reduced. In the tenth paper, Chen, Kwon, Mao, Yuan and Leung propose a Reliable Energy-Efficient Routing (REER) protocol. Based on the geographical information, REER's design harnesses the advantage of high node density, and it relies on the collective efforts of multiple cooperative nodes to deliver data, without depending on any individual ones. Therefore, it can ensure the scalability, reliability and energy efficiency. In the eleventh paper, Kim, Wang and Madihian analyse the energy efficiency of a few representative cooperative Multi-Input Multi-Output (MIMO) transmission schemes. They conclude that the cooperative MIMO schemes achieve significant performance enhancement over the Single-Input Single-Output (SISO) scheme when the circuit power consumption is small compared to the transmit power. However, when the circuit power consumption is not negligible, the cooperative MIMO may not be energy efficient in the cross-layer setting compared to the SISO scheme.

The last paper by Peter, Langendörfer and Piotrowski consider whether the Public Key Cryptography (PKC) algorithm is affordable for small battery powered sensor devices. They evaluate the power consumptions of various PKC approaches with respect to calculations and transmissions of signatures, etc. Their findings indicate that software realisations of PKC lead to relatively long duty cycles (operating intervals) which in turn require significant amount of energy. In contrast, the energy required for computation is negligible if the PKC is performed by power efficient hardware accelerators.

In closing, the guest editors would like to thank all the authors who responded to the Call for Papers, regardless of whether their papers have been included in this issue or not due to space limitations. The editors would also like to acknowledge the contribution of many experts who participated in the review process and provided helpful and valuable suggestions to the authors on improving the content and presentation of the articles. The advice and support from Dr. Y. Xiao, Editor-in-Chief of the *International Journal of Sensor Networks* is greatly appreciated.