Low-Power, Intelligent, and Secure Solutions for Realization of Internet of Things

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Editorial
Low-Power, Intelligent, and Secure Solutions for Realization of Internet of Things

I. Introduction

THIS special issue aims to provide a timely discussion on the technical trends and challenges of circuits and systems on Internet of Things (IoT). Rapid advancement of networking technologies together with extreme miniaturization of computing and communication devices enable emerging and exciting applications and services that connect the cyber and physical worlds. In the future, digital sensing, communication, and processing capabilities will be ubiquitously embedded into everyday objects, turning them into the IoT. In this new paradigm, smart devices will collect data, relay the information or context to each other, and process the information collaboratively in a machine-to-machine (M2M) manner.

There are many applications of this new paradigm, such as the following.

1) Economical agriculture: In a farm field, remote bug traps can detect the outbreak of pests and initiate spreading the proper amount of pesticide. This will reduce the chance of overspreading and potential damage to the crops.
2) Vehicle safety: Sensors on a car can help drivers realize the potential risk of running into each other; in particular, sensors and inter-vehicle communication can help us see what we cannot see. With timely and proper warning, some vehicle accidents can be avoided.
3) Assisted living: The population is aging. The need to take care of more elders is increasing. Sensors can help us monitor the health condition of elders and properly provide help (e.g., reminders of missing a dose, warning of high blood pressure, requesting medical emergency).

This paradigm shift creates numerous challenges and opportunities for engineering. For example, in the future, enormous numbers of sensors will be deployed. The costs of servicing such sensors will be a major concern. It is often incredibly expensive to replace sensor batteries once they are in the field. Therefore, one major challenge is to design low power sensor that require no battery change. For example, if a sensor is deployed on an animal for tracking purposes, the battery of the sensor should outlive the animal. This creates a demand for **energy-efficient designs and energy harvesting**, including low-power circuits and communication protocols.

Connected devices (sensors) can produce oceans of data. We need layers of intelligence to transform this data into wisdom. In this new computing era, **analysis of data and its context** will play a key role. Many analytic algorithms assume that the system has all the data on the server. However, it takes power and bandwidth to communicate the data to the server. Moreover, not all the data are important or useful. Architecture-wise, it is natural for sensor data to be processed in a hierarchical and distributed fashion. Data may be analyzed and fused in sensors or gateways before arriving at the data center to save energy and bandwidth. If the system can recognize what context is important in the very beginning, it only needs to transmit the relevant information to the backend server or the cloud. As devices become more computationally capable, intelligent computation may easily be distributed among the sensors and the backend servers.

None of us likes to expose our personal or confidential information to the public. We also do not want people to provide false information that changes the proper action of the system. Therefore, another challenge on this topic is **data security and privacy**. Data security and privacy is always a major concern, even more important in IoT, which touches many aspects of human life. Some low-cost devices have a limited budget to implement strong security or cryptography features. These lightweight devices can become the weakest links in the system. Conventional firewalls that provide network security by blocking malicious traffic can no longer work in IoT because of its decentralized nature. If the lightweight devices are not properly secured, the data they produce cannot be fully trusted. Attackers may provide false information that alters the behaviors of the system. Designing low-cost and scalable crypto algorithms and hardware accelerators is crucial. A system-level security analytics and self-adaptive security policy framework are also needed.

II. Organization and Overview

In order to deploy end-to-end solutions for intelligent/secure interaction among connected devices, IoT requires research from multiple disciplines. There is a huge space of discussions for this special issue to cover. We have prioritized different topics, as described below.

This special starts with five papers in the area of energy-efficient designs, including low-power circuits and new communication protocols. First, one of the most energy consuming components in wake-up driven radio is the active power of the wake up receiver. "Ultra Low Power Wake-Up Radio using Envelope Detector and Transmission Line Voltage Transformer" by Nilsson and Svensson presents a simple and robust oscillator-free Wake-Up radio, which offers a trim-free solution easily implemented in an ordinary CMOS process without adding any external lumped components. Second, proper sleep scheduling can save energy for wireless devices; however, QoS may be sacrificed. Therefore, "An Energy-Efficient Sleep Scheduling with QoS Consideration in 3GPP LTE-Advanced Networks for Internet of Things" by Liang *et al.* presents how to jointly optimize the energy saving and QoS guarantee. Third, for sensors/devices with unpredictable quantity and quality of the energy source, it is a challenge to design the embedded microprocessors. "Synchronous-logic and Asynchronous-logic 8051 Microcontroller Cores for Powering the Internet of Things:

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A Comparative Study on Dynamic Voltage Scaling and Variation Effects" by Chang *et al.* compares the speed, energy, and chip area between a conventional synchronous-logic and a quasi-delay-insensitive asynchronous-logic 8051 microcontroller. For IoT applications that are more prone to process, voltage, and temperature variations, the asynchronous design outperforms the synchronous design despite of larger chip area. Fourth, for sensors/devices with uncertain energy source, it is critical to know the available energy levels. "Voltage Sensing Using an Asynchronous Charge-to-Digital Converter for Energy- Autonomous Environments" by Ramezani *et al.* presents a novel voltage-sensing circuit that does not need a reference voltage, which is often hard to obtain in the energy harvesting devices. Fifth, "Design of an internet-accessible WSN Platform for Long-Term Environmental Monitoring" by Lazarescu presents a generic framework of designing an Internet-accessible WSN platform for long-term environment monitoring. Various trade-offs between platform features and specifications are identified and analyzed. The development methodology can be reused for other application domains.

Then, this special issue includes three papers on low-power data and context analysis and processing. First, among different sensors used in IoT, video sensors can provide the richest amount of information. However, the power consumption and bandwidth requirement from video sensors may hinder the wide deployment of them wirelessly. In order to provide a foundation of the future distributed video sensor designs, "Power Consumption Analysis for Distributed Video Sensors in Machine-to-Machine Networks" by Chien *et al.* analyzes and compares the power consumption distributed video coding versus the state-of-the-art H.264 coding. Second, in order to enable good context analysis on the energy-constrained devices, it is important to consider algorithm-level optimization. "Cascading Signal-Model Complexity for Energy-Aware Detection" by Jun and Jones presents an analysis and design of low-power detection algorithm. Similarly, for accurate signal classification, it often needs high computational complexity. However, in reality, the classification must run at an extremely low power in order to survey for a long period of time. "Design of a Low-Power On-Body ECG Classifier for Remote Cardiovascular Monitoring Systems" by Chen *et al.* provides a comprehensive analysis the trade-off between power consumption and classification accuracy. Furthermore, it presents a practical implementation of the classifier.

This special issue concludes with three papers on system reliability and security. First, sensors may fail due to many reasons. In body sensor network, it is even more challenging because of energy constraint. "Fault-Tolerant and Low-Power Sampling Schedules for Localized BASNs" by Goudar, and Potkonjak presented a comprehensive study from application requirements to system designs. Second, future vehicles will be fully connected using the sensors and communication capabilities. This will be a significant realization of IoT. "Challenges and Opportunities for Securing Intelligent Transportation System" by Zhao *et al.* examines the risks faced by the current intelligent transportation system architecture and public key infrastructure for vehicle communication. The analysis calls for future research directions in order to achieve the full potential for future intelligent transportation system. Third, conventional wisdom believes symmetric-key cryptography is less expensive than public-key cryptography. However, public-key cryptography actually has a lower total cost of ownership because of cost savings in provision, deployment, and management. Furthermore, public-key cryptography can be more energy efficiency because public-key-based security protocols usually use less communication than their symmetric-key-based counterparts. "Securing M2M with post-quantum public-key cryptography" by Shih *et al.* demonstrates the feasibility of using hardware-based public-key cryptography to provide data security in IoT applications.

III. Selection Process of the Special Issue

This special issue is highly selective and competitive. We received 46 initial submissions. After the first round of reviews, 15 manuscripts were asked to be revised. After the second round of reviews, to satisfy the high-quality requirements of IEEE Journal of Emerging and Selected Topics in Circuits and Systems, we chose only 11 out of those 15 papers. The acceptance rate of 24% is one of the lowest within the past couple of years. The goal of this special issue is to discuss the technical trends and challenges of circuits and systems on low-power, reliable, and secure solutions for realization of IoT. Many papers, although they are excellent papers, were not selected due to limited relevance to the scope of the special issue.

We would like to thank everyone who submitted papers to the special issue for their efforts, and express our regret that due to limited space and the need for balanced coverage, not all high-quality submissions could be included. We also thank the authors for their valuable contributions, and the anonymous reviewers for their help in ensuring the quality of the special issue.

We would like to express our most faithful gratitude to the IEEE JETCAS Editor-in-Chief, Prof. Massoud Pedram, Deputy-Editor-in-Chief Prof. Manuel Delgado-Restituto, Editorial Assistant Annie Yu, and Senior Editorial Board Members of IEEE Journal of Emerging and Selected Topics for Circuits and Systems, for encouragement and support on this special issue.

We sincerely hope that you enjoy this special issue and find its contents informative and useful.

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Dr. Chen has served in many technical leadership roles in IEEE Circuits and Systems Society and IEEE Signal Processing Society. He is the Chair of Multimedia Systems and Applications technical committee of IEEE Circuits and Systems Society, 2012–2013. He has served as an editorial board member for over five journals, including IEEE JOURNAL ON EMERGING AND SELECTED TOPICS IN CIRCUITS AND SYSTEMS, IEEE TRANSACTIONS ON CIRCUIT AND SYSTEM FOR VIDEO TECHNOLOGY, IEEE TRANSACTIONS ON CIRCUIT AND SYSTEM—PART I, IEEE SIGNAL PROCESSING MAGAZINE, and IEEE TRANSACTIONS ON MULTIMEDIA. He has served as a program committee member of over 50 international conferences, on cyber-physical systems, multimedia, video compression/communication, image/signal processing, VLSI circuits and systems, parallel processing, and software optimization. He is an invited participant to 2002 Frontiers of Engineering Symposium (National Academy of Engineering) and to 2003 German–American Frontiers of Engineering Symposium (Alexander von Humboldt Foundation).

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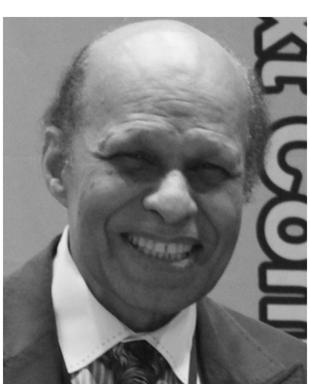

Magdy A. Bayoumi (F'99) received the B.Sc. and M.Sc. degrees in electrical engineering from Cairo University, Cairo, Egypt, the M.Sc. degree in computer engineering from Washington University, St. Louis, MO, USA, and the Ph.D. degree in electrical engineering from the University of Windsor, Windsor, ON, Canada.

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Prof. Koushanfar is a recipient of the PECASE Award, the ACM SIGDA Outstanding New Faculty Award, the National Academy of Science Kavli Foundation fellowship, MIT Technology Review TR-35, a best paper award at Mobicom, and early career awards from the National Science Foundation, the Office of Naval Research, the Army Research Office, and the Defense Advanced Research Projects Agency (DARPA).