Battery Life Extension Techniques for Energy Harvesting-Based IoT Devices

Abstract

Many Internet-of-Things (IoT) applications require the deployment of a large number of wireless sensing nodes with limited computing and energy storage capabilities. Therefore, to successfully set up a network with uninterrupted service, the judicious application of battery-life extension techniques is required. These techniques involve both energy harvesting and energy conservation approaches. In this tutorial, different battery life extension methods are discussed, with a specific focus on the *perception* and *network* layers of the IoT architecture. The first part consists in an overview of basic principles and of the different energy harvesting devices available (photovoltaic, piezoelectric, thermoelectric, electromagnetic, solar-thermoelectric and fuel cell). Devices for energy storage are also discussed. Then, the concept of Power Management is introduced and the design of single-input and multiple-input energy harvesting circuits is presented. The second part of the tutorial focuses on data driven, duty-cycling, Dynamic Power Management (DPM) energy conservation techniques that can be implemented at the system level. Examples from both the speaker's research work and from the state-of-the-art literature will be given.

***Keywords*:** Energy harvesting, Dynamic Power Management, Internet-of-Things, Wireless Sensor Network

Learning Objectives

At the end of the tutorial presentation, the attendants will be able to:

1. Recognize the importance of battery lifetime for the success of IoT applications
2. Identify the main components of a sensor node architecture
3. Classify diverse lifetime extension schemes for IoT networks
4. Appraise and select a particular lifetime extension technique suitable to their own application
5. Investigate novel systems, circuits and transducers for energy harvesting and IoT applications

Intended Audience

The target audience of this tutorial are:

- Researchers and practicing engineers interested in theoretical and practical hardware design techniques for Internet of Things applications
- Newcomers interested in familiarizing with current research on energy harvesting circuits and sensor node systems
- Electrical and Computer Engineering graduate and undergraduate students interested in obtaining a comprehensive survey on the design of battery-less IoT systems

Tutorial content

The proposed length of the tutorial is half-day (4 hours). A 5-to-10-minute break is contemplated at the end of each hour. The content and tentative timeline schedule is:

1. Introduction (1 Hour)
   a. What is the Internet of Things?
   b. Challenges to the IoT: Implications of limited battery lifetime
   c. IoT sensor node typical architecture

2. Energy Harvesting (1 Hour)
   a. Sources for energy harvesting
   b. Energy storage devices
   c. Energy Harvesting Power Management Units: Single and Multiple-Input
3. Energy conservation schemes (1 Hour)
   a. Survey of techniques for lifetime extension of IoT devices
   b. Data driven and duty cycling techniques
4. Examples of energy conservation schemes (1 Hour)

Speaker Biography

Johan J. Estrada-López was born Mérida, México. He received the B.Sc. in electrical engineering from the Mérida Institute of Technology, Mérida, in 2001, the M.Sc. in electrical engineering from the Center of Advanced Research and Studies (CINVESTAV), Guadalajara, México, in 2003, and the Ph.D. in electrical engineering in 2019 from Texas A&M University, College Station, TX, USA. He has been a recipient of both the TI Jack Kilby Excellence and the Silicon Labs Fellowship at Texas A&M University. From 2012 to 2013, he worked as a Layout Design Engineer with Vidatronic Inc. In 2017, he was a Design Intern with the Power Delivery Group, Intel Corporation, Hillsboro, OR, USA. In 2019, he worked as a Postdoctoral Researcher at the Analog and Mixed-Signal Center, Texas A&M University. He is currently an Associate Professor of Electrical and Computer Engineering with the Autonomous University of Yucatán, in México. His research interests include energy harvesting circuits and power management for Wireless Sensor Networks and Internet of Things applications.

Speaker's Recent Work in the Tutorial's Topic

Z. Zeng, **J. J. Estrada-López**, B. Wang and E. Sánchez-Sinencio, "A CMOS Energy Harvesting Interface Circuit with Cycle-to-Cycle Frequency-to-Amplitude Conversion MPPT for Centimeter-Scale Wind Turbine," in *IEEE Trans. on Circuits and Systems I: Regular Papers*, vol. 68, no. 9, pp. 3587-3597, Sept. 2021, doi: 10.1109/TCSI.2021.3087790

A. Castillo-Atoche *et al*., "An Energy-Saving Data Statistics-Driven Management Technique for Bio-Powered Indoor Wireless Sensor Nodes," in *IEEE Trans. on Instrumentation and Measurement*, vol. 70, pp. 1-10, 2021, Art no. 9507010, doi: 10.1109/TIM.2021.3063187

J. J. Estrada López, A. Castillo Atoche and E. Sanchez Sinencio, "Design and Fabrication of a 3-D Printed Concentrating Solar Thermoelectric Generator for Energy Harvesting Based Wireless Sensor Nodes," in *IEEE Sensors Letters,* vol. 3, no. 11, pp. 1-4, Nov. 2019, Art no. 5500904

A. Abuellil, **J. J. Estrada Lopez**, A. V. Bommireddipalli, A. Costilla Reyes, Z. Zeng and E. Sanchez-Sinencio, "Multiple-Input Harvesting Power Management Unit with Enhanced Boosting Scheme for IoT Applications," in *IEEE Trans. on Industrial Electronics*, vol. 67, no. 5, pp. 3662-3672, May 2020

J. J. Estrada Lopez, A. Abuellil, A. Costilla Reyes, M. Abouzied, S. Yoon and E. Sanchez-Sinencio, "A Fully Integrated Maximum Power Tracking Combiner for Energy Harvesting IoT Applications," in *IEEE Trans. on Industrial Electronics*, vol. 67, no. 5, pp. 3662-3672, May 2020

Z. Zeng, **J. J. Estrada-López**, M. A. Abouzied and E. Sánchez-Sinencio, "A Reconfigurable Rectifier with Optimal Loading Point Determination for RF Energy Harvesting from -22 dBm to -2 dBm," in *IEEE Trans. on Circuits and Systems II: Express Briefs* , vol. 67, no. 1, pp. 87-91, Jan. 2020, doi: 10.1109/TCSII.2019.2899338.