Signals and Communication Technology

Hossam Mahmoud Ahmad Fahmy

Wireless Sensor Networks

Energy Harvesting and Management for Research and Industry

Springer

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Hossam Mahmoud Ahmad Fahmy
Faculty of Engineering
Department of Computer Engineering
and Systems
Ain Shams University
Cairo, Egypt

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Dedicated to my family;
parents, brothers and sister with whom I grew up warmly…
wife and daughters who gave my life a caring taste…

Dedication is not only for who are in our world…

Preface

Writing a book is tempting, many ideas and topics, idea after idea, and topic upon topic, what to elaborate, which to mention, the reader must find a satisfying answer, enough knowledge; overlooking and going-by are painful choices for the author, space is limited, and a tough decision is to be made, without compromising what should be transferred to the audience. Writing a scientific book is navigating, across the Nile, the Mediterranean, the Atlantic and the Indian oceans, in boat and in glass submarine, looking and searching for known and unknown species, appreciating diversified colors and variety of sizes, collecting for a near benefit and for the future. I navigated for the second time, explored, day and night, when cold and hot, whether windy or breezing, without tolerating a least chance to know and learn.

Networking is a field of integration, hardware and software, protocols and standards, simulation and testbeds, wired and wireless, VLSI and communication, energy harvesting and management, an orchestrated harmony that collaborates dependably, all for the good of a connected well-performing network. That is the charm of networking, of life in a civilization that recognizes differences and goes on.

This book focuses on the concepts of energy, and energy harvesting and management techniques for WSNs; a meticulous care has been accorded to the definitions, terminologies, and protocols. Definitions and terminologies are made clear without leaning on the relaxing assumption that they are already known or easily reachable, and the reader is not to be diverted from the main course. Neatly drawn figures assist in viewing and imagining the offered topics. To make energy-related topics felt and seen, the adopted technologies as well as their manufacturers are presented in detail. With such a depth, this book is intended for a wide audience, and it is meant to be helper and motivator, for the senior undergraduates, postgraduates, researchers, and practitioners; concepts and energy-related applications are laid out, research and practical issues are backed by the appropriate literature, and new trends are put under focus. For senior undergraduate students, it familiarizes with conceptual foundations and practical project implementations. Also, it is intended for graduate students making a thesis and in need of specific knowledge on WSNs and the related energy harvesting and management techniques. Moreover, it is targeting researchers and practitioners interested in features and applications of WSNs, and on the available energy harvesting and management projects and testbeds.

Three parts form the backbone of this book. Part I (Concepts and Energy Harvesting) includes Chap. 1 and 2, for a review of WSN concepts and in-depth presentation of the energy harvesting techniques. Part II (Energy Management Perspectives) embodies Chap. 3 and Chaps. 4–6 for a thorough analysis of the three perspectives on energy management: specifically, duty-cycling, data-driven, and mobility-based approaches. Part III (Harvesting and Management Projects and Testbeds) containing Chaps. 7–9 brings practice to theory through energy harvesting and management projects and testbeds.

Part IV is a single concluding chapter. Chapter 10 ignites the launch into the wide realm of WSNs, research, and implementation of energy-focused protocols and techniques for energy harvesting and management. A longer WSN lifetime is the prime target.

Exercises at the end of each chapter are not just questions and answers; they are not limited to recapitulate ideas. Their design objective is not bound to be a methodical review of the provided concepts, but rather as a motivator for lot more of searching, finding, and comparing beyond what has been presented in this book.

Talking numbers, this book extends over ten chapters and embodies 188 acronyms, 238 colored figures, 41 tables, and above 650 references.

With the advance of technology, writing a book is becoming easier, and information is attainable; but it is certainly tedious, and details and depth are not to be missed within a comforting accuracy. Reader trust cannot be waived. Every bit of knowledge included in this book is checked and rechecked multiple times, no accidental slips. A book, any book, is a step in a long path sought to be correct, precise as possible, nonetheless errors are non-escapable, and they are avoided iteratively, with follow-up and care.

The preface is the first get-together between the author and the audience, it is the last written words, and it is lying in the ground after the end line, to restore taken breath, to enjoy relaxing after long painful efforts, mentally and physically, to relax in preparation for a new game. Bringing a book to life consumes months and months, days and nights, events after events, familial, social, and at the wide world of technology, sports, and politics. This book has seen much and recorded some. An author has his ups and downs, as everybody, but he is visible like nobody. Could he manage to hide some of his letdowns? Yes he has to, unlike anybody, for the sake of his book, his readership.

A book is a whole life, maybe in the current, in the past, or in future. The author has many dreams, completing the current chapter, reaching the last chapter, agreeing on the book cover, handing the book to the publisher, receiving the manuscript for revision, talking royalties, …

Writing with care and feelings can be a title for my books. Authoring is a duty, a passion, an exhausting ordeal with mostly a moral reward…

If you find somebody talking to himself, tumbling, wearing a differently colored pair of shoes, don't laugh at him, he is probably writing a book…

Cairo, Egypt

Hossam Mahmoud Ahmad Fahmy
email: Hossam.fahmy@ieee.org

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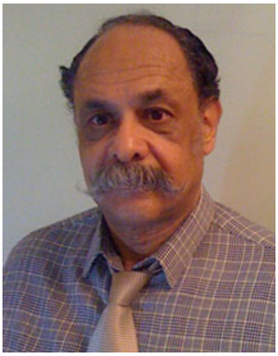

Prof. Hossam M. A. Fahmy Professor of Computer Engineering served as Chair of the Computer Engineering and Systems Department, Faculty of Engineering, Ain Shams University, Cairo, Egypt, from 2006 to 2008 and from 2010 to 2012. He participates in many academic activities in Egypt and abroad. Prof. Fahmy has published and refereed extensively in Springer, Elsevier and IEEE journals and in several refereed international conferences. His teaching and research areas are focused on computer networks, MANETs, WSNs, VANETs, fault tolerance, software, and Web engineering. He authored Wireless Sensor Networks: Concepts, Applications, Experimentation and Analysis, book published by Springer, 2016.

He founded and chaired the IEEE International Conference on Computer Engineering and Systems (ICCES) from 2006 to 2008 and from 2010 to 2013. He is Senior IEEE Member, IEEE Region 8 Distinguished Visitor (2013–2015) and (2015–2018), Member of the Distinguished Visitor Committee of the IEEE Computer Society, and Member in the Cloud Computing Special Technical Community of the IEEE Computer Society. He speaks Arabic, French, and English.

List of Acronyms

2-DOF	2-degree of freedom
ACC	Active congestion control
ADC	Analog-to-digital converter
AEA	Adaptive election algorithm
AFECA	Adaptive fidelity energy-conserving algorithm
AINS	Autonomous Intelligent Networks and Systems
AMRP	Average minimum reachability power
AODV	Ad hoc on-demand distance vector
ARMA	Autoregressive–moving-average
ARQ	Automatic repeat request
ASCENT	Adaptive self-configuring sensor networks topologies
ASK	Amplitude-shift keying
AWP	Asynchronous wakeup protocol
B-MAC	Berkeley-MAC
BER	Bit error rate
BTU	British thermal unit
CC	Control/charger
CCA	Clear channel assessment
CDS	Connected dominating set
CEC	Cluster-based energy conservation
CLUDDA	Clustered diffusion with dynamic data aggregation
CNES	Centre National d'Etudes Spatiales
CNS	Center at nearest source
COP	Computer operating properly
CPLD	Complex programmable logic device
CSMA/CA	Carrier sense multiple access with collision avoidance
CTS	Clear to send
CUSUM	Cumulative sum
DAC	Digital-to-analog converter
DBMAC	Delay bounded medium access control

DBP	Derivative-based prediction
DCF	Distributed coordination function
DCO	Digitally controlled oscillator
DCS	Data collection and location system
DOD	Depth of discharge
DOP	Dilution of precision
DPM	Dynamic probabilistic model
DS	Data send
DSDV	Highly dynamic destination-sequenced distance-vector routing
DSF	Damage Sensitive Feature
DSP	Digital signal processing
DSR	Data success ratio
DT-MSM	Delay-tolerant mobile sink model
DTN	Delay-tolerant networking
EADAT	Energy-aware distributed aggregation tree
ECN	Explicit contention notification
EDD	Enhanced directed diffusion
EDLC	Electric double-layer capacitor
EEDC	Energy-efficient data collection
EGS	Electronic grade silicon
EH	Energy harvesting
EM-EH	Electromagnetic energy harvester
EMACS	EYES-medium access control protocol for WSNs
EMI	Electromagnetic interference
ESR	Equivalent series resistance
FAR	FloodNet adaptive routing
FFT	Fast Fourier transform
FLAMA	Flow-aware medium access
FPA	Fast path algorithm
FR	Flame retardant
FRTS	Future request to send
FV	Frequency to voltage
GIF	Graphics interchange file
GIT	Greedy incremental tree
GLPK	GNU Linear Programming Kit
GMRE	Greedy maximum residual energy
GPIO	General-purpose input/output
HCL	High contention level
HEED	Hybrid energy-efficient distributed clustering
HEH	Hybrid energy harvesting
I2C	Inter-Integrated Circuit
ID	Identification
IDC	Insulation-displacement connector
IMD	Implantable biomedical device

ISI	Information Sciences Institute
JPEG	Joint Photographic Experts Group
JTAG	Joint Test Action Group
L-MAC	Lightweight medium access protocol
LCL	Low contention level
LCS	Location-based clustering scheme
LEACH	Low-energy adaptive clustering hierarchy
Li-ion	Lithium-ion
LiPo	Lithium polymer
LPL	Low power listening
MACAW	Media access protocol for wireless LAN
MANET	Mobile ad hoc network
MC3	Multicamera coordination and control
MDC	Mobile data collector
MDS	Minimal dominating set
MEH	Micro-energy harvester
MEMS	Microelectromechanical system
MILP	Mixed integer linear programming
MPP	Maximum power point
MPPT	Maximum power point tracking
MR	Mobile relay
MRE	Mean relative error
MS	Mobile sink
MSEMS	Macro-sensor electromechanical system
MSM	Mobile sink model
MSN	Maximum slot number
MSPR	Multiple shortest path routing
MTS	More to send
MULE	Mobile ubiquitous LAN extension
NAMA	Node activation multiple access
NAV	Network allocation vector
NiCd	Nickel–cadmium
NiMH	Nickel–metal hydrid
NOAA	National Oceanic and Atmospheric Administration
NP	Neighbor protocol
OEM	Original equipment manufacturer
ONR	Office of Naval Research
OOK	ON-OFF keying
OWFA	Optimal wakeup frequency assignment
P-MOSFET	P-type metal–oxide–semiconductor field-effect transistor
PAC/C	Power-aware computing and communications
PAMAS	Power-aware multi-access protocol with signaling
PANEL	Position-based aggregator node election
PCB	Printed circuit board
PDF	Probability density function

PEGASIS	Power-efficient gathering in sensor information system
PLA	Piecewise linear approximation
PLC	Programmable logic controller
POR	Polynomial regression
PREMON	Prediction-based monitoring
PTX	Primary transmitter
PRX	Primary receiver
PSM	Power saving mode/Power saving mechanism
PTT	Platform terminal transmitter
PTZ	Pan-tilt-zoom
PV	Photovoltaics
PWM	Pulse width modulation
RBS	Reference broadcast synchronization
RC	Reservoir capacitor
RCA	Reservoir capacitor array
RFID	Radio frequency identification
RINAS	Restricted input network activation scheme
RLE	Run length encoding
RLS	Recursive least square
RM	Random movement
ROI	Region of interest
RTC	Real-time clock
RTS	Request to send
RTWAC	Radio triggered wakeup with addressing capability
S-LEC	Sequential lossless entropy compression
S-MAC	Sensor-MAC
SAF	Similarity-based adaptive framework
SB	Solar biscuit
SC	Switched capacitor
SEP	Schedule exchange protocol
SHM	Structural health monitoring
SI	Standard international
SLA	Sealed lead acid
SMA	SubMiniature version A
SMP	Sensor Management Protocol
SMPS	Switched-mode power supply
SNGF	Stateless non-deterministic geographic forwarding
SNR	Signal-to-noise ratio
SOI	Silicon on insulator
SPIN	Sensor protocols for information
SSM	Static sink model
STC	Standard testing condition
SWIM	Shared wireless infostation model
T-MAC	Timeout-MAC
TAG	Tiny aggregation service

TDFN	Thin, dual-in-line flat package, no lead
TDMA	Time-division multiple access
TEG	Thermoelectric power generator
TEH	Thermal energy harvesting
TMPO	Topology management by priority ordering
TRAMA	Traffic-adaptive medium access protocol
TSR	Total solar radiation
TTL	Time to live
UASN	Underwater acoustic sensor network
UCLA	University of California, Los Angeles
USC	University of Southern California
VAR	Value-added reseller
VEH	Vibration-based energy harvester
WDT	Watchdog timer
WID	Wireless impedance device
WLAN	Wireless LAN
WMN	Wireless mesh network
WPAN	Wireless personal area network
WSF	Wakeup schedule function
WSN	Wireless sensor network
WSN-ME	WSN with mobile element
μ-TEG	Micro-scale thermoelectric generator

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