Energy Harvesting Communications

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Principles and Theories

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To my parents

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Preface

Wireless communication has provided unprecedented convenience for our daily lives over the past few decades. This convenience largely comes from the replacement of data cables with wireless interconnections. However, the remaining power cables or batteries used in conventional wireless systems are still restricting their mobility or lifetime and hence, are preventing them from being deployed in more and wider applications. Meanwhile, wireless power has emerged as a recent innovation to substitute the power cable. Many breakthroughs have been made. The innovation is further boosted by green communications that aims to meet the governmental targets for emission reduction by harvesting solar energy, wind energy, and other renewable sources.

Given these recent development, it is reasonable to adopt wireless power or energy harvesting in communications so that the last cable in wireless systems can be removed to exploit the full potential of wireless communications. This leads to energy harvesting wireless communications, which is the topic and the motivation of this book.

The use of harvested energy brings big challenges to system designs. First and most importantly, the energy source becomes random or dynamic. This leads to fundamental changes to wireless system designs. Secondly, energy harvesting changes the characteristics of signals and channels utilized in system designs. On the other hand, the use of harvested energy also creates great opportunities. It allows perpetual and sustainable operations of wireless systems. Many conventional wireless systems can be upgraded by adding the energy harvesting functionality to improve their sustainability. For example, sensor networks can use energy harvesting to prolong their lifetime. Cognitive radios can exchange energy for transmission opportunities. Relaying networks can encourage more idle nodes to be involved in relaying by offering them wireless power.

Chapters 1–5 focus on the challenges brought by energy harvesting in wireless communications. Chapters 6–8 focus on different wireless applications enhanced by energy harvesting. Specifically, this book will follow the flow of energy from the energy source, to the energy harvester, to the wireless device, and then to the application. Chapter 1 gives a brief introduction of energy harvesting wireless communications. Chapter 2 discusses different energy sources harvested for wireless communications. Chapter 3 examines the energy harvesters used for two widely used sources. Chapters 4 and 5 study the physical layer and upper layer of the energy harvesting wireless device, respectively. Chapters 6–8 investigate wireless powered communications, energy harvesting cognitive radios and energy harvesting relaying as applications. The whole book focuses on principles and theories rather than systems and implementations.

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I apologize in advance for any errors that may have occurred and welcome any comments and suggestions for further improvements.

Yunfei Chen
Coventry, UK, May 2018

Acronyms

3G	Third Generation
4G	Fourth Generation
5G	Fifth Generation
AC	Alternating Current
AF	Amplify-and-Forward
AP	Access Point
AWGN	Additive White Gaussian Noise
BCR	Bit Correct Rate
BER	Bit Error Rate
BFSK	Binary Frequency Shift Keying
BPSK	Binary Phase Shift Keying
CDF	Cumulative Distribution Function
CDMA	Code Division Multiple Access
CR	Cognitive Radio
CSMA/CA	Carrier Sensing Multiple Access with Collision Avoidance
D2D	Device-to-Device
DF	Decode-and-Forward
DPS	Dynamic Power Splitting
DPSK	Differential Phase Shift Keying
EA-MAC	Energy Adaptive Media Access Control
EME	Average Energy to Minimum Eigenvalue
EWMA	Exponentially Weighted Moving Average
FCC	Federal Communications Commission
GSM	Global System for Mobile Communications
HAP	Hybrid Access Point
HE-MAC	Harvest-then-Transmit Media Access Control
LOS	Line-Of-Sight
MAC	Media Access Control
MB	Moment-Based
ME	Maximum Eigenvalue
MIMO	Multiple-Input-Multiple-Output
MME	Maximum-to-Minimum Eigenvalue
ML	Maximum Likelihood
MSE	Mean Squared Error
NLOS	Non-Line-Of-Sight

NOMA	Non-Orthogonal Multiple Access
NRMSE	Normalized Root Mean Squared Error
OFDM	Orthogonal-Frequency-Division-Multiplexing
OFDMA	Orthogonal Frequency Division Multiple Access
OMA	Orthogonal Multiple Access
OSI	Open Systems Interconnection
PAPR	Peak-to-Average-Power Ratio
PB	Power Beacon
PDF	Probability Density Function
PHY	Physical
PS	Power Splitting
PSK	Phase Shift Keying
PU	Primary User
PV	Photovoltaic
QoS	Quality of Service
RC	Resistor-Capacitor
RD	Relay to Destination
RF	Radio Frequency
RFID	Radio Frequency Identification
ROC	Receiver Operating Characteristics
SIR	Signal-to-Interference Ratio
SINR	Signal-to-Interference-plus-Noise Ratio
SNR	Signal-to-Noise Ratio
SR	Source to Relay
STC	Standard Testing Conditions
SWIPT	Simultaneous Wireless Information and Power Transfer
TCP/IP	Transmission Control Protocol/Internet Protocol
TDD	Time-Division-Duplex
TDMA	Time Division Multiple Access
TS	Time Switching
QoS	Quality of Service
WCMA	Weather Conditioned Moving Average
WPC	Wireless Powered Communications
WSN	Wireless Sensor Network