Smartphone Energy Consumption

With an ever-increasing number of applications available for mobile devices, battery life is becoming a critical factor in user satisfaction. This practical guide provides you with the key measurement, modeling, and analytical tools needed to optimize battery power by developing energy-aware and energy-efficient systems and applications.

As well as the necessary theoretical background and results from the field, this hands-on book also provides real-world examples, practical guidance on assessing and optimizing energy consumption, and details of prototypes and possible future trends. Uniquely, you will learn about energy optimization of both hardware and software in one book, enabling you to get the most from the available battery power.

Covering experimental system design and implementation, the book supports assignment-based courses with a laboratory component, making it an ideal textbook for graduate students. It is also a perfect guidebook for software engineers and systems architects working in industry.

Online resources available at www.cambridge.org/tarkoma.

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Smartphone Energy Consumption

Modeling and Optimization

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Contents

Preface

Energy modeling and optimization are very important parts of mobile and wireless application development. Recent studies suggest that the battery life of a smartphone has become a critical factor in user satisfaction. Typical mobile applications today consume much more energy than is strictly necessary because of the suboptimal use of the smartphone's hardware by the software.

This book provides guidelines for smartphone users, methodologies for researchers, and in-depth knowledge of smartphone power management for the public at large. The techniques presented in the book are necessary for developing energy-aware and energy-efficient systems and applications. The book provides the necessary theoretical background and results from the field, and also practical guidance on assessing and optimizing energy efficiency.

In this book we study the following two questions: What is the power consumption of smartphones and applications, and what are the potential solutions for optimizing smartphone power consumption?

Mobile device power management is facing new challenges posed by the revolutionary development of mobile networks, devices, and applications. Smartphones are complex systems, and it is hard to anticipate user behavior and the way the operating system (OS) and applications use the underlying hardware resources. Thus, advanced techniques are needed, first to understand the power-consumption behavior, and then to optimize the hardware/software design to improve energy efficiency.

The book has been written with three key aims in mind:

- Holistic: This book is not strictly about smartphone hardware or software; both are taken into account when considering energy optimization.
- Forward-looking: Some of the advanced techniques detailed in the book have been recently proposed in the scientific community.
- Hands-on: This book provides many practical examples.

Organization of the book

The book has three parts:

- Part I: Understanding energy consumption. This part presents the overview and the basic concepts relating to energy measurement. We concentrate on the basics of the

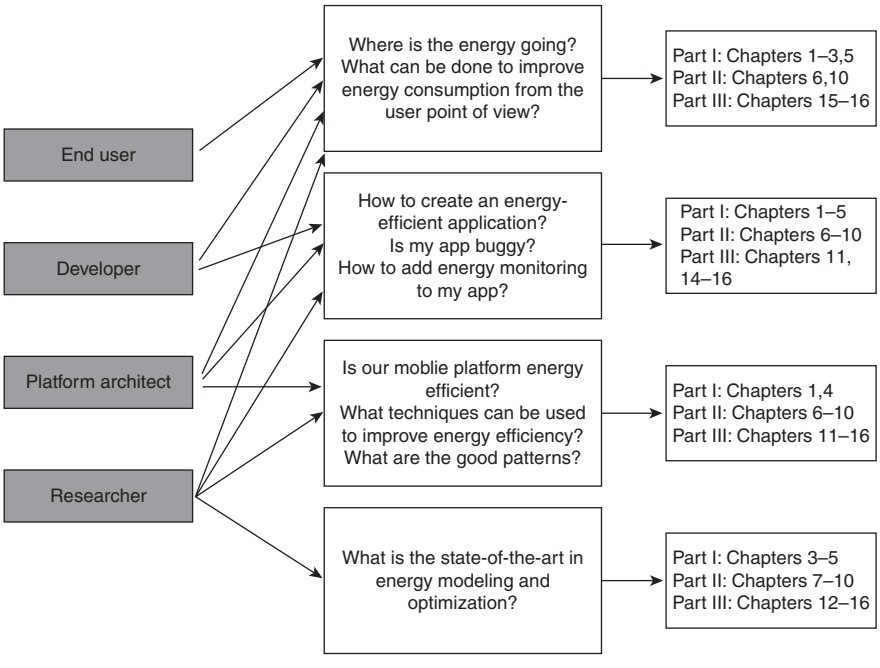
energy consumption of smartphones, that is, where the energy goes and why. We describe multiple ways to measure the energy consumption.

- Part II: Energy management and conservation. This part gives more detail by focusing on the main energy profiling, modeling, and conservation techniques. We consider power management in existing platforms for smartphones. We cover the three main platforms, that is, iOS, Android, and Windows Phone, and also provide examples based on others. We study different techniques to conserve energy by optimizing the design and implementation of mobile software.
- Part III: Advanced energy optimization. This part considers more advanced optimization techniques, such as traffic scheduling, use of multiple network interfaces, and mobile cloud offloading. We conclude the part and the book with a discussion of future trends.

Reading the book

The figure below presents the key target audiences for the book: the end users of smartphones, mobile developers and platform architects, and students and researchers. The figure outlines the key questions that the book addresses as well as the pertinent chapters.

End users are typically interested in maximizing the remaining operating time of their device, and also knowing what use cases are energy consuming. This book explains



The key target audiences for the book

how energy is consumed in smartphones, which can help the end users to adjust the use of their smartphones to extend the battery life. Chapter 5 focuses on human–battery interaction and getting the most out of remaining battery life.

Mobile developers are interested in creating energy-efficient applications and identifying potential energy-related bottlenecks and bugs in the applications. This requires the use of energy-efficient solutions, as well as energy-profiling and analysis techniques. We cover well-known solutions for application energy profiling and diagnostics starting with basic energy measurement solutions. Most of these solutions and techniques are covered in Part II of the book.

Platform architects are interested in OS- and middleware-level solutions for power management. These solutions are examined in Parts II and III. Part III focuses on advanced platform-level solutions such as computational offloading and traffic scheduling and offloading.

Researchers are interested in the state-of-the-art techniques and either applying them to solve a specific problem or extending them beyond the state of the art. The book provides a summary of the state of the art for them. These techniques are covered in Parts II and III.

Contributors

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Abbreviations

3GPP	3rd Generation Partnership Project
ACF	Autocorrelation Function
ACK	Acknowledgment
ACPI	Advanced Configuration and Power Interface
ADSL	Asymmetric Digital Subscriber Line
ADU	Application Data Unit
AFH	Adaptive Frequency-Hopping
AIDL	Android Interface Description Language
AMOLED	Active-Matrix Organic Light-Emitting Diode
AP	Access Point
API	Application Programming Interface
APIC	Advanced Programmable Interrupt Controller
APM	Advanced Power Management
AR	Autoregressive
ARIMA	Autoregressive Integrated Moving Average
ARO	Application Resource Optimizer
BIOS	Basic Input/Output System
BLE	Bluetooth Low Energy
CAM	Continuously Active Mode
CBR	Constant Bit-Rate
CC/CV	Constant Current/Constant Voltage
CCD	Charge-Coupled Device
CCLF	Cold Cathode Fluorescent Lamps
CDMA	Code Division Multiple Access
CIL	Common Intermediate Language
CISC	Complicated Instruction Set Computer
CLI	Common Language Infrastructure
CLR	Common Language Runtime
CLT	Central Limit Theorem
CMOS	Complementary Metal Oxide Semiconductor
CPC	Continuous Packet Connectivity
CPU	Central Processing Unit
CSMA/CA	Carrier Sense Multiple Access with Collision Avoidance

D2D	Device to Device
DASH	Dynamic Adaptive Streaming over HTTP
DDI	Device Driver Interface
DDMS	Dalvik Debug Monitor Server
DEF	Dalvik Executable Format
DHCP	Dynamic Host Configuration Protocol
DMA	Direct Memory Access
DMS	Domain Management System
DNS	Domain Name System
DOD	Depth of Discharge
DPM	Dynamic Power Management
DPS	Dynamic Power Switching
DRAM	Dynamic Random Access Memory
DSA	Digital Signature Algorithm
DSP	Digital Signal Processor
DVFS	Dynamic Voltage and Frequency Scaling
ECDSA	Elliptic Curve Digital Signature Algorithm
eNBs	Evolved Node B
EPS	Evolved Packet System
ESSID	Electronic Service Set Identifier
FD	Fast Dormancy
FSM	Finite State Machine
GPRS	General Packet Radio Service
GPU	Graphics Processing Unit
GSM	Global System for Mobile Communications
HAL	Hardware Abstraction Layer
HBI	Human–Battery Interaction
HPC	Hardware Performance Counter
HSPA	High Speed Packet Access
i.i.d.	independent identically distributed
IoT	Internet of Things
IP	Internet Protocol
IPC	Inter-Process Communication
IPS LCD	In-Plane Switching Liquid Crystal Display
ISP	Image Signal Processor
ISP	Internet Service Provider
ITU	International Telecommunication Union
IVA	Image, Video, Audio
JNI	Java Native Interface
JVM	Java Virtual Machine
LCD	Liquid Crystal Display
Li-Ion	Lithium-Ion

Li-Po	Lithium-Polymer
LTE	Long Term Evolution
LTE-A	Long Term Evolution Advanced
M2M	Machine-to-Machine
MA	Moving Average
MAC	Medium Access Control
MAPE	Mean Absolute Percentage Error
McBSP	Multichannel Buffered Serial Port
MIMO	Multiple Input, Multiple Output
MIPI	Mobile Industry Processor Interface
MSE	Mean Square Error
NDK	Native Development Kit
NEP	Nokia Energy Profiler
NFC	Near Field Communication
NFI	Newton Forward Interpolation
NiMH	Nickel–Metal Hydride
NMSE	Normalized Mean Square Error
NSRM	Network Socket Request Manager
OCV	Open-Circuit Voltage
OLED	Organic Light-Emitting Diode
OFDMA	Orthogonal Frequency Division Multiple Access
OMAP	Open Media Applications Platform
OS	Operating System
P2P	Peer to Peer
PACF	Partial Autocorrelation Function
PCA	Principal Component Analysis
PDA	Personal Data Assistant
PDU	Protocol Data Unit
PS	Packet-Switched
PSM	Power-Saving Mechanism or Power-Saving Mode
PSMP	Power Save Multi-Poll
QQ	Quality and Quantity
QoE	Quality of Experience
QoS	Quality of Service
RF	Radio Frequency
RIL	Radio Interface Layer
RISC	Reduced Instruction Set Computer
RMS	Root Mean Square
RRC	Radio Resource Control
RSA	Rivest, Shamir, Adleman
RSSI	Received Signal Strength Indicator
RTT	Round-Trip Time

SDK	Software Development Kit
SER	Standard Error of Regression
SMPS	Spatial Multiplexing Power Save
SNR	Signal-to-Noise Ratio
SOC	State of Charge
SoC	System on a Chip
SOD	State of Discharge
SOH	State of Health
SSL	Secure Sockets Layer
TCP	Transmission Control Protocol
TCP/IP	Transmission Control Protocol/Internet Protocol
TDM	Time-Division Multiplexing
TDMA	Time Division Multiple Access
TFT	Thin Film Transistor
TLS	Transport Layer Security
UDP	User Datagram Protocol
ULP	Ultra Low Power
UMTS	Universal Mobile Telecommunications Service
USB	Universal Serial Bus
VoIP	Voice-over-IP
VoLTE	Voice over LTE
WCDMA	Wideband Code Division Multiple Access
WLAN	Wireless Local Area Network
WNI	Wireless Network Interface