

Contents

<i>Preface</i>	<i>page</i> ix
<i>List of abbreviations</i>	xiii
Part I Understanding energy consumption	1
1 Introduction	3
1.1 Overview and the environment	3
1.2 Smartphone hardware and software	7
1.3 Mobile communications	11
1.4 Anatomy of a smartphone	15
1.5 Summary	21
<i>References</i>	21
2 Energy and power primer	23
2.1 Energy and power	23
2.2 Ideal voltage source and open-circuit voltage (OCV)	25
2.3 Power computation	25
2.4 Radio power	28
2.5 Duty cycle	29
2.6 Mathematical tools	30
2.7 Summary	34
<i>References</i>	34
3 Smartphone batteries	36
3.1 Overview	36
3.2 Static battery parameters	38
3.3 Dynamic battery parameters	39
3.4 Smart batteries	41
3.5 Chargers	43
3.6 Discharge current	47
3.7 State of charge (SOC) measurement	50
3.8 Open-circuit voltage (OCV) models	51

3.9	Summary	56
	<i>References</i>	57
4	Energy measurement	59
4.1	Hardware- and software-based energy measurement	59
4.2	Measuring smartphone subsystems	60
4.3	Estimating device lifetime	62
4.4	Energy measurement techniques	62
4.5	Hardware energy measurement and ground truth	65
4.6	Worked examples	66
4.7	Summary	72
	<i>References</i>	72
5	On human behavior and energy efficiency	73
5.1	Human–battery interaction	73
5.2	Human factors in battery-awareness applications	74
5.3	Experiment: Getting the most of remaining battery life	76
5.4	Summary	79
	<i>References</i>	80
	Part II Energy management and conservation	81
6	Overview	83
6.1	Methodology	83
6.2	Power modeling	85
6.3	Power optimization	89
6.4	Summary and organization of Part II	90
	<i>References</i>	90
7	Smartphone subsystems	92
7.1	CPU and SoC	92
7.2	Display	108
7.3	Wireless network interfaces	110
7.4	Sensors	125
7.5	Camera	129
7.6	Summary	132
	<i>References</i>	133
8	Mobile operating systems	137
8.1	Overview	137
8.2	iOS	140
8.3	Windows Phone OS	144

8.4	Firefox OS	147
8.5	Android	148
8.6	Energy-aware OS research prototypes	152
8.7	Summary	155
	<i>References</i>	159
9	Power modeling	162
9.1	Methodology	162
9.2	Deterministic power models of Wi-Fi network interface	167
9.3	Statistical system-level power models of smartphones	179
9.4	eProf: fine-grained system call tracing energy profiler	187
9.5	Summary	189
	<i>References</i>	189
10	Power profilers	192
10.1	Overview	192
10.2	Survey of energy profilers	194
10.3	Android battery management framework: battery statistics	196
10.4	Offline energy profiling in a laboratory	199
10.5	Online on-device energy profilers with offline support	204
10.6	Online on-device energy profilers	207
10.7	Energy diagnosis engines	212
10.8	Summary	220
	<i>References</i>	222
	Part III Advanced energy optimization	225
11	Overview	227
11.1	Underlying power-management techniques alone are not enough	227
11.2	The importance of timing and context	229
11.3	Taking full advantage of the smartphone capabilities	231
11.4	Getting a little help from friends	231
11.5	Summary	232
12	Traffic scheduling	234
12.1	How scheduling saves energy	234
12.2	Shaping traffic to “race to sleep”	235
12.3	Scheduling background traffic	244
12.4	Context-aware scheduling	250
12.5	Scheduling multiple devices	259
12.6	Summary	261
	<i>References</i>	262

13	Exploiting multiple wireless network interfaces	264
13.1	How using multipleWNIs saves energy	264
13.2	Tracking movement to optimize the discovery energy	264
13.3	Using hints from otherWNIs	268
13.4	Sleep and wake-ups to reduce idle power	269
13.5	Energy-aware wireless network interface selection	269
13.6	Use case: Energy awareness in mobile traffic offloading	270
13.7	Summary	276
	<i>References</i>	277
14	Mobile cloud offloading	281
14.1	Computation offloading	281
14.2	Communication offloading	288
14.3	Where to offload: centralized cloud vs. distributed cloud	293
14.4	Summary	294
	<i>References</i>	295
15	Example scenarios for energy optimization	297
15.1	Video streaming	297
15.2	Energy-efficient sensing through sampling	304
15.3	Security	308
15.4	Summary	312
	<i>References</i>	312
16	Future trends	315
16.1	Future smartphone	315
16.2	Battery	316
16.3	Future smartphone SoC	318
16.4	Fifth-generation mobile networks (5G)	318
16.5	Mobile OS and platform	320
16.6	Application domains	321
16.7	Summary	322
	<i>References</i>	322
	Appendix A An energy profile application	324
A.1	Included files	324
	<i>Index</i>	331