

A MODEL FOR POWER EFFICIENCY OF MOBILE
DEVICES THROUGH LIGHTWEIGHT METHOD
LEVEL COMPUTATIONAL OFFLOADING

MUSHTAQ ALI

DOCTOR OF PHILOSOPHY

UNIVERSITI MALAYSIA PAHANG

SUPERVISOR'S DECLARATION

We hereby declare that we have checked this thesis and in our opinion, this thesis/project* is adequate in terms of scope and quality for the award of the degree of *Doctor of Philosophy in Computer Sciences.

(Supervisor's Signature)

Full Name : Dr. Mohamad Fadli Zolkipli
Position : Senior Lecturer
Date : 21 Feb 2018



(Co-supervisor's Signature)

Full Name : Prof. Dr. Jasni Mohamad Zain
Position : Professor
Date : 19 Feb 2018



STUDENT'S DECLARATION

I hereby declare that the work in this thesis is based on my original work except for quotations and citation which have been duly acknowledged. I also declare that it has not been previously or concurrently submitted for any other degree at Universiti Malaysia Pahang or any other institutions.

(Student's Signature)

Full Name : MUSHTAQ ALI

ID Number : PCC13009

Date : 14 Feb 2018

A MODEL FO POWER EFFICIENCY OF MOBILE DEVICES THROUGH
LIGHTWEIGHT METHOD LEVEL COMPUTATIONAL OFFLOADING

MUSHTAQ ALI

Thesis submitted in fulfillment of the requirements
for the award of the degree of
Doctor of Philosophy

Faculty of Computer Systems & Software Engineering
UNIVERSITI MALAYSIA PAHANG

FEBRUARY 2018

Dedicated to

“My Mom and Dad (Late)”

I learned from my Mother: “Where there is a will there is a way”

&

I learned from my Father: “Always do the best job, your reputation
worth more than a quick profit”

ACKNOWLEDGEMENT

All virtues and praise to Almighty Allah, Whose blessings are unlimited. I am thankful to my current research supervisor Dr. Mohamad Fadli Zolkipli who guided me at each step in the beginning till end to pursue my research. I pay my tribute to my previous research supervisor Prof. Dr. Jasni Mohamad Zain for her kind support to deal with all the challenges pertaining to this research. Her wise guidance led my way from my first step of this research till the last one; particularly in the process of data acquisition and lab instruments. Apart from my research supervisors, I am very thankful to Associate Professor Dr. Mazlina Abdul Majid, Assistant Professor Dr. Nawsher Khan and my dear friend Mr. Waris Khan who helped me in starting my PhD journey and supported me throughout. I also received the cooperation of Dr. Mansoor Abdullateef Abdulgaber, Assistant Professor at University Malaysia Pahang and Dr. Muhammad Shiraz Assistant Professor in Federal Urdu University Islamabad Pakistan. I would like to extend my gratitude to my uncle Noor Rahman Afghani without whom guidance I would not be here today. I am very thankful to my brother Ashraf Ali who supported me and taught me how to tackle the hard time. My thanks further goes to university friends Dr. Gran Badshah, Shahid Anwar and Riaz ul Haq, who helped me in overcoming the hurdles during my studies. The prime credit goes to the University Malaysia Pahang that funded this work under research grant GRS 110334. I also wish to express my sincere gratitude and appreciation to my family specially my wife and two beautiful kids Manahil Ali and Abdul Moiz, who endured my absence with patience and never let me have any idea of those problems that they faced persistently during the whole period I remained abroad.

TABLE OF CONTENTS

	Page
DECLARATION	
TITLE PAGE	
ACKNOWLEDGEMENT	iii
ABSTRAK	iv
ABSTRACT	v
TABLE OF CONTENTS	vi
LIST OF TABLES	x
LIST OF FIGURES	xii
LIST OF ABBREVIATION	xv
CHAPTER 1 INTRODUCTION	
1.1 Overview	1
1.2 Motivation	1
1.3 Problem Background	3
1.4 Problem Statement	6
1.5 Research Questions	7
1.6 Goal and Objectives	8
1.7 Scope of Research	8
1.8 Thesis Organization	9
CHAPTER 2 LITERATURE REVIEW	
2.1 Overview	11
2.2 Background	11
2.2.1 Mobile Computing	12
2.2.2 Cloud Computing	13
2.2.3 Mobile Cloud Computing	16
2.3 Approaches for Augmenting Mobile's Resources	17

2.3.1	Generation of New Hardware Resources	18
2.3.2	Execute Program Slowly	18
2.3.3	New Applications for Resources Constrained Devices	19
2.3.4	Hardware and Software Management Techniques	19
2.4	Taxonomy of Batteries Augmentation Techniques	21
2.4.1	Hardware Level Augmentation	22
2.4.2	Software Level Augmentation	23
2.5	An Analysis of CPU Clock Time, Execution Time and Power Consumption	29
2.6	Computational Offloading	31
2.6.1	Energy Saving Computational Offloading	32
2.6.2	Metrics of Computational Offloading Approaches	34
2.6.3	Taxonomy of Computational Offloading / Cyber foraging Approaches	37
2.7	Related Works	42
2.7.1	Previous Research on Enhancing Mobile's Efficiency	43
2.8	Review of Computational Offloading Frameworks	57
2.8.1	Whole Application Migration Frameworks	57
2.8.2	Virtual Machine (VMs) Migration Frameworks	58
2.8.3	Method Level Migration Frameworks	58
2.9	Analytical Analysis of Method Level Computational Offloading Frameworks	65
2.10	Summary	70

CHAPTER 3 METHODOLOGY

3.1	Overview	72
3.2	Research Approach	72
3.2	Research Phases	76
3.2.1	Planning Phase	78
3.2.2	Analysis, Design and Implementation Phase	79
3.2.3	Evaluation Phase	87
3.2.4	Comparative Analysis	88
3.3	Summary	89

CHAPTER 4 DESIGN AND IMPLEMENTATION

4.1	Overview	90
4.2	Computational Offloading and Execution Time	90
4.3	The Model	92
	4.3.1 Mobile Component	97
	4.3.2 Server Component	102
	4.3.3 Communication	103
4.4	Operational Logic	103
	4.4.1 Operational Logic of REST-Offload Model	103
	4.4.2 Application Execution Flow of REST-Offload Model	105
	4.4.3 Proposed Algorithm for the Selection of Pre-defined Parameters	109
4.5	Evaluation of the Model	112
	4.5.1 Experiment Setup	113
	4.5.2 Prototype	117
	4.5.3 Data Collection and Data Processing	118
	4.5.4 Data Collected by Executing Application at Local Mobile Device	119
	4.5.5 Data Collected by Offloading Application using Traditional Offloading Techniques	122
	4.5.6 Data Collected by Offloading Application using REST-Offload	124
4.6	Summary	126

CHAPTER 5 RESULTS AND DISCUSSION

5.1	Overview	127
5.2	Analysis of Application Execution at Local Mobile Device	127
5.3	Analysis of Application Executed through Traditional Offloading Methods	131
5.4	Analysis of Application Execution using REST-Offload Method	136
5.5	Comparison of ET/TT of Matrix Multiplication B/W Local Execution, Traditional Offloading and REST-Offload	140
	5.5.1 Execution Time (ET) Result Comparison of Samsung Galaxy A5	140
	5.5.2 Execution Time (ET) Result Comparison of ASUS Zenfone5	142
5.6	Comparison of Energy Consumption Cost of Matrix Multiplication between Local Execution, Traditional Offloading and REST-Offload	145

5.6.1	Energy Consumption (EC) Result Comparison of Samsung Galaxy A5	145
5.6.2	Energy Consumption (EC) Result Comparison of ASUS Zenfone5	148
5.7	Comparison of Execution Time (ET) and Energy Consumption (EC) between REST-Offload and DCOF	151
5.8	ET and EC Comparison of Samsung Galaxy A5 with ASUS Zenfone5 for all Three Scenarios	153
5.9	Efficiency Comparison of REST-Offload against Existing Frameworks	160
5.9.1	Efficiency Comparison of Execution Time	161
5.9.2	Efficiency Comparison of Energy Consumption	162
5.10	Specification Comparisons of REST-Offload and Existing Approaches	163
5.11	Threat to Validity	166
5.11.1	Usage Scenario	166
5.11.2	<i>DuTs</i> Threats	167
5.11.3	Single Hop Surrogate Threats	170
5.11.4	Energy and Time Estimating Tools Threats	170
5.9	Summary	171
CHAPTER 6 CONCLUSION AND FUTURE WORK		
6.1	Overview	173
6.2	Discussion	173
6.2.1	Revisit of the Research Objectives	174
6.2.2	Contribution of the Research	177
6.2.3	The Scalability of the Research	178
6.5	Limitations and Future Work	178
REFERENCES		180

LIST OF TABLES

Table 2.1	A Comparison of advancement between Static Servers and Mobile Devices with a gap of 5 years	16
Table 2.2	Analysis of the Previous Research Work on Resources Augmentation of Mobile Devices	54
Table 2.3	Comparative Review of Computational Offloading Models	60
Table 2.4	Summary of Method Level Computational Offloading Frameworks	66
Table 3.1	Energy Consumption Cost EC1 of Offloading Matrix Multiplication Service in Traditional Computational Offloading	82
Table 3.2	Time Consumption Cost TC1 of Offloading Matrix Multiplication Service in Traditional Computational Offloading	85
Table 3.3	The Experiment Setup of Previous Research Works	87
Table 4.1	The Hop-Count and Average Delay	93
Table 4.2	Local Execution Time of Prototype Application at Samsung Galaxy A5	120
Table 4.3	Local Execution Time of Prototype Application at ASUS Zenfone5	120
Table 4.4	Energy Consumption (EC) of Prototype Application at Samsung Galaxy A5 through Local Execution	121
Table 4.5	Energy Consumption of Prototype Application at ASUS Zenfone5 through Local Execution	121
Table 4.6	Execution Time of Prototype Application Execution through Traditional Offloading using Samsung Galaxy A5	122
Table 4.7	Execution Time of Prototype Application Execution through Traditional Offloading using ASUS Zenfone5	122
Table 4.8	Energy Consumption Cost of Prototype Application Execution through Traditional Offloading using Samsung Galaxy A5	123
Table 4.9	Energy Consumption Cost of Prototype Application Execution through Traditional Offloading using ASUS Zenfone5	123
Table 4.10	Execution Time of Prototype Application Execution through REST-Offload Method using Samsung Galaxy A5	125
Table 4.11	Execution Time of Prototype Application Execution through REST-Offload Method using ASUS Zenfone5	125
Table 4.12	Energy Consumption Cost of Prototype Application Execution through REST-Offload Method using Samsung Galaxy A5	125

Table 4.13	Energy Consumption Cost of Prototype Application Execution through REST-Offload Method using ASUS Zenfone5	125
Table 5.1	Comparison of ET / TT of Samsung Galaxy A5 between Local Execution, Traditional Offloading and REST-Offload	140
Table 5.2	P% of ET / TT of REST-Offload Method for Samsung Galaxy A5 using the equation, $Y = P\% * X$, against Local Execution and Traditional Offloading	142
Table 5.3	Comparison of ET of ASUS Zenfone5 between Local Execution, Traditional Offloading and REST-Offload	143
Table 5.4	P% of ET / TT of REST-Offload Method for ASUS Zenfone5 using the equation, $Y = P\% * X$, against Local Execution and Traditional Offloading	144
Table 5.5	Comparison of Energy Consumption Cost between Local Execution, Traditional Offloading and REST-Offload for Galaxy A5	145
Table 5.6	P% of Energy Consumption of REST-Offload Method for Samsung Galaxy A5 using the equation, $Y = P\% * X$, against Local Execution and Traditional Offloading	147
Table 5.7	Comparison of Energy Consumption Cost between Local Execution, Traditional Offloading and REST-Offload for ASUS Zenfone5	148
Table 5.8	P% of Energy Consumption of REST-Offload Method of ASUS Zenfone5 using the equation, $Y = P\% * X$, against Local Execution and Traditional Offloading	150
Table 5.9	Comparison of ET between REST-Offload and DCOF	151
Table 5.10	Comparison of EC between REST-Offload and DCOF	152
Table 5.11	ET Comparison of Samsung Galaxy A5 and ASUS Zenfone5.	154
Table 5.12	Specifications of Samsung Galaxy A5 and ASUS Zenfone5	155
Table 5.13	EC Comparison of Samsung Galaxy A5 and ASUS Zenfone5.	158
Table 5.14	Efficiency Comparison of Execution Time	161
Table 5.15	Efficiency Comparison of Energy Consumption	162
Table 5.16	Comparative Analysis of REST-Offload against Others	164

LIST OF FIGURES

Figure 2.1	Framework of Mobile Computing	13
Figure 2.2	Service-Oriented Layered Architecture of Cloud Computing	15
Figure 2.3	A Typical Framework of Mobile Cloud Computing	17
Figure 2.4	Mobile's Resources Enhancing Approaches	21
Figure 2.5	Taxonomy of Mobile's Battery Augmentation Techniques	22
Figure 2.6	Clone-Cloud Framework	29
Figure 2.7	Relationship between B, D and C	33
Figure 2.8	Metrics of Cyber Foraging	34
Figure 2.9	Execution Flow of Computational Offloading	35
Figure 2.10	Taxonomy of Cyber Foraging/Computational Offloading	37
Figure 2.11	CloneCloud- Architectural and System Framework	44
Figure 2.12	Cloudlet Architectural Model	46
Figure 2.13	Context-Aware Power Manager	49
Figure 2.14	CALEEF Architectural Model	50
Figure 3.1	Research Flowchart	73
Figure 3.2	Operational Model	77
Figure 3.3	EC Cost of Matrix Multiplication in Traditional Offloading	82
Figure 3.4	ET Cost of Matrix Multiplication in Traditional Offloading	85
Figure 4.1	Computational Offloading and Execution Time/Turnaround Time	92
Figure 4.2	Mobile Devices Connected to Remote Servers through Single hop, limited multi-hop and multi-hop	94
Figure 4.3	Model of REST-Offload	96
Figure 4.4	Operational Logic of REST-Offload Model	104
Figure 4.5	Application Execution Flow of the Proposed Model	107
Figure 4.6	Flow of the Selection of Predefine Parameters	110
Figure 4.7	The Environment of Experimental Offloading Scenario	114
Figure 4.8	A Screen Short of Monsoon Power Monitor Application Tools	116
Figure 4.9	Use of Monsoon Power Monitor in Experiments for Power Consumption Readings	117
Figure 5.1	Execution Time (ms) of Matrix Multiplication in Local Mobile Device Samsung Galaxy A5	128

Figure 5.2	Execution Time (ms) of Matrix Multiplication in Local Mobile Device ASUS Zenfone5	129
Figure 5.3	Local Energy Consumption (J) of Matrix Multiplication by Samsung Galaxy A5	130
Figure 5.4	Local Energy Consumption (J) of Matrix Multiplication using ASUS Zenfone5	131
Figure 5.5	Execution Time of Matrix Multiplication in Traditional Offloading by Samsung Galaxy A5	133
Figure 5.6	Execution Time of Matrix Multiplication in Traditional Offloading by ASUS Zenfone5	133
Figure 5.7	Energy Consumption (J) of Matrix Multiplication in Traditional Offloading by Samsung Galaxy A5	134
Figure 5.8	Energy Consumption (J) of Matrix Multiplication in Traditional Offloading by ASUS Zenfone5	135
Figure 5.9	Execution Time (ms) of Matrix Multiplication in REST-Offload using Samsung Galaxy A5	136
Figure 5.10	Execution Time (ms) of Matrix Multiplication in REST-Offload using ASUS Zenfone5	138
Figure 5.11	Energy Consumption (J) of Matrix Multiplication in REST-Offload using Samsung Galaxy A5	138
Figure 5.12	Energy Consumption (J) of Matrix Multiplication in REST-Offload using ASUS Zenfone5	139
Figure 5.13	Execution Time (ms) Comparison of Matrix Multiplication of all Three Scenarios using Samsung Galaxy A5	141
Figure 5.14	Execution Time (ms) Comparison of Matrix Multiplication of all Three Scenarios using ASUS Zenfone5	143
Figure 5.15	Energy Consumption (J) Comparison of Matrix Multiplication of all Three Scenarios using Samsung Galaxy A5	147
Figure 5.16	Energy Consumption (J) Comparison of Matrix Multiplication of all Three Scenarios using ASUS Zenfone5	149
Figure 5.17	ET (ms) Comparison of Matrix Multiplication of between DCOF and REST-Offload	152

Figure 5.18	EC (J) Comparison of Matrix Multiplication of between DCOF and REST-Offload	153
Figure 5.19	Execution Time (ms) Comparison of Galaxy A5 and ASUS Z5 in Local Execution	156
Figure 5.20	Execution Time (ms) Comparison of Galaxy A5 and ASUS in Traditional Offloading	156
Figure 5.21	Execution Time (ms) Comparison of Galaxy A5 and ASUS in REST-Offload	157
Figure 5.22	Energy Consumption (J) Comparison of Galaxy A5 and ASUS Z5 in Local Execution	159
Figure 5.23	Energy Consumption (J) Comparison of Galaxy A5 and ASUS Z5 in Traditional Offloading	159
Figure 5.24	Energy Consumption (J) Comparison of Galaxy A5 and ASUS Z5 in REST-Offload	160
Figure 5.25	Efficiency Comparison of Execution Time	161
Figure 5.26	Efficiency Comparison of Energy Consumption	163

LIST OF ABBREVIATIONS

3D	Three Dimensions
3G	Third Generations
4G	Fourth Generations
ADB	Android Debug Bridge
AMOLED	Active Matrix Organic Light Emitting Diode
AP	Access Point
API	Application Programming Interface
AWS	Amazon Web Services
BTS	Base Transceiver Station
BW	Bandwidth
CALEEF	Context Aware Light Weight Energy Efficient Framework
CasCap	Cloud Assisted Context-Aware Power Management
CC	Cloud Computing
CDB	Context Detection Block
CEO	Chief Executive Officer
CF	Cyber Foraging
CI	Confidence Interval
CPU	Central Processing Unit
DiET	Distributed Execution Transformer
DOCs	Documents
DPM	Dynamic Power Management
DuT	Device under Test
EC2	Elastic Cloud Computing
ECC	Energy Consumption Cost
ECC	Elastic Cloud Computing
EDGE	Enhanced Data for GSM Evolution
ET	Execution Time
FA	Fidelity Adaptation
FTP	File Transfer Protocol
GB	Giga Byte
GHz	Giga Hurts

GPRS	Global Packet Radio Service
GPS	Global Positioning System
GPU	Graphical Processing Unit
GSM	Global System for Mobiles
HTC	High Tech Computer Corporation
HTTP	Hypertext Transfer Protocol
I/O	Input Output
IaaS	Infrastructure-as-a-Service
IDE	Integrated Development Environment
IEEE	Institute of Electrical and Electronic Engineering
IT	Information technology
J	Joule
LCD	Liquid Crystal Display
Li-ion	Lithium-Ion
mAh	Milliamp ere per Hour
MCC	Mobile Cloud Computing
MP3	Moving Picture Experts Group Layer-3 Audio
ms	Millisecond
mV	Millivolt
mW	Milli-watt
OS	Operating System
P2P	Point to Point
PaaS	Platform-as-a-Service
PC	Personal Computer
PDA	Personal Digital Assistance
QoS	Quality of Services
RAM	Random Access Memory
REST	Representational State Transfer
RPC	Remote Procedure Calls
RSD	Relative Standard Deviation
RTT	Round Trip Time
S3	Simple Storage Services
SaaS	Software-as-a-Service

SD	Standard Deviation
SDK	Software Development Kit
SID	Smart Internet Device
SOAP	Simple Object Access Protocol
T_0	Zero Throughputs
TC	Time Cost
TCP	Transfer Control Protocol
T_M	Maximum Throughputs
T_N	Normal Throughputs
TT	Turnaround Time
UDP	User Datagram Protocol
UI	User Interface
UMTS	Universal Mobile Telecommunication System
USB	Universal Serial Bus
VM	Virtual Machine
WAN	Wide Area Network
Wi-Fi	Wireless Fidelity
Wi-Max	Worldwide Interoperability for Microwave Access
WLAN	Wireless Local Area Network
WWW	World Wide Web