



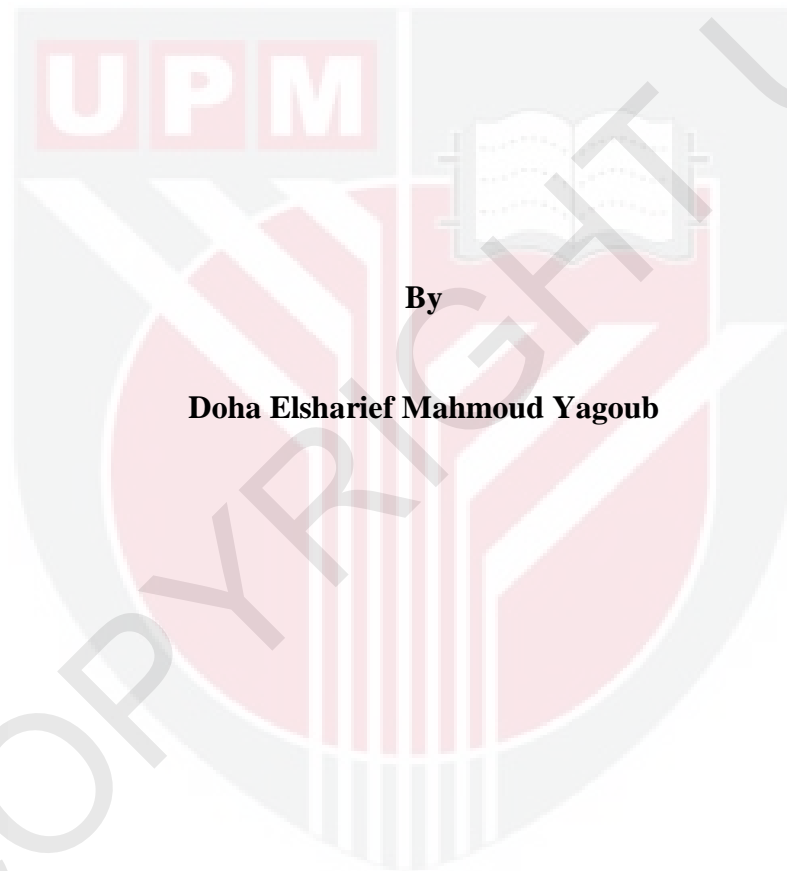
**UNIVERSITI PUTRA MALAYSIA**

**MULTI-LEVEL MOBILE CACHE CONSISTENCY SCHEMES  
BASED ON APPLICATION REQUIREMENTS**

**DOHA ELSHARIEF MAHMOUD YAGOUB**

**FSKTM 2012 1**

**MULTI-LEVEL MOBILE CACHE CONSISTENCY SCHEMES BASED ON  
APPLICATION REQUIREMENTS**



**By**

**Doha Elsharief Mahmoud Yagoub**

**Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia,  
in Fulfilment of the Requirements for the Degree of Doctor of Philosophy**

**January 2012**

DEDICATION

*To the Soul of my beloved father Elsharief Mahmoud,  
"Rahimuh Allah"  
To my beloved mother Suad Abdeljaleel*



Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

**MULTI-LEVEL MOBILE CACHE CONSISTENCY SCHEMES BASED ON APPLICATION REQUIREMENTS**

By

**DOHA ELSHARIEF MAHMOUD YAGOUB**

**January 2012**

**Chair: Hamidah Ibrahim, PhD**

**Faculty: Faculty of Computer Science and Information Technology**

In mobile environment, maintaining cache consistency is challenging due to the inherited limitations of mobile environment. In particular, there is a need for supporting multiple levels of consistency (strict and weak levels) when maintaining mobile cache to enhance the performance of data access in a mobile environment.

The multiple levels of cache consistency provided by the existing scheme are based on the mobile client interest, i.e. each mobile client is responsible to determine the consistency level of each of its cached data items based on its current requirements on that item. However, this is not an appropriate idea since the consistency of the cached data items should be determined based on the requirements of the application on that item. The mobile application may allow a degree of weak consistency to some cached data items and some critical cached data items have to be up to date with data in the source. To address this issue, this thesis proposes a new stateful scheme to maintain cache consistency in the mobile environment called Application

Based Multi-Level Mobile Cache Consistency Scheme (ABMMCCS). ABMMCCS is considered the first scheme that provides multiple levels of cache consistency based on the application requirements and therefore is suitable to various mobile applications.

The other issue addressed in this thesis, is the degradation in the efficiency of the stateful schemes when the application system is used by a large workgroup of mobile users with sharing data. Degradation appears in the extra overhead of the base server to assure the delivering of the updates to the massive number of clients and the increasing in the uplink bandwidth consumption. Towards this an Adaptive Dynamic Application Based Multi-level Mobile Cache Consistency Scheme (AD-ABMMCCS) is introduced. AD-ABMMCCS scheme has proven that it enhances the efficiency of the stateful scheme ABMMCCS when the mobile application is used by a large group of users with sharing data.

The proposed schemes are evaluated analytically and experimentally. The results show that under all consistency levels, ABMMCCS has significantly reduced the overhead of the mobile client and the base server and achieved better utilization to the wireless network bandwidth compared to Multi-Level Cache Consistency Protocol (MCCP) scheme. Also the results reflect the high rate of saving in the uplink bandwidth achieved when applying AD-ABMMCCS.

Abstrak tesis dikemukakan Kepada Senat Universiti Putra Malaysia Sebagai memenuhi keperluan untuk ijazah Doktor Flasafah

**SKIM KONSISTENSI CACHE MOBIL PELBAGAI PERINGKAT  
BERASASKAN APLIKASI**

Oleh

**DOHA ELSHARIEF MAHOMUD YAGOUB**

**Januari 2012**

**Pengerusi: Hamidah Ibrahim, PhD.**

**Fakulti: Sains Komputer dan Teknologi Maklumat**

Dalam persekitaran bergerak, menyelenggara konsistensi cache adalah mencabar disebabkan oleh batasan yang diwarisi daripada persekitaran bergerak. Khususnya, terdapat satu keperluan untuk menyokong pelbagai peringkat konsistensi (peringkat tegas dan lemah) apabila menyelenggara cache bergerak untuk meningkatkan prestasi capaian data dalam satu persekitaran mobil.

Pelbagai peringkat konsistensi cache yang disediakan oleh skim sedia ada adalah berdasarkan kepentingan pelanggan bergerak iaitu setiap pelanggan mobil adalah bertanggungjawab untuk menentukan tahap konsistensi untuk setiap item data cache berdasarkan keperluan semasa pada item itu. Walau bagaimanapun, ini bukan satu idea yang sesuai memandangkan konsistensi item data mestilah ditentukan berasaskan kepada keperluan aplikasi pada item itu. Aplikasi mobil membenarkan suatu tahap konsistensi lemah untuk beberapa item data cache dan beberapa item data cache kritikal perlu terkini dengan data dalam sumber. Untuk menangani isu ini,

tesis ini mencadangkan satu skim *stateful* yang baharu untuk menyelenggara konsistensi cache dalam persekitaran bergerak dipanggil Aplikasi Berasaskan Skim Konsistensi Cache Bergerah Pelbagai Peringkat (ABMMCCS). ABMMCCS dianggap skim pertama menyediakan pelbagai peringkat konsistensi cache berasaskan keperluan aplikasi dan oleh itu adalah sesuai untuk pelbagai aplikasi mobil.

Isu lain yang ditangani dalam tesis ini adalah degradasi dalam kecekapan skim *stateful* apabila sistem aplikasi digunakan oleh kumpulan kerja pengguna mobil yang besar dengan perkongsian data. Degradasi muncul dalam overhead tambahan pelayan asas untuk memastikan penyampaian kemas kini kepada bilangan besar pelanggan dan peningkatan dalam penggunaan lebar jalur uplink. Berikutan ini, Aplikasi Dinamik Mudah Suai Berasaskan Skim Konsistensi Cache Bergerah Pelbagai Peringkat (AD-ABMMCCS) telah diperkenalkan. Skim AD-ABMMCCS telah membuktikan bahawa ia meningkatkan kecekapan skim *stateful* ABMMCCS apabila aplikasi mobil digunakan oleh sekumpulan besar pengguna dengan perkongsian data.

Skim yang dicadangkan telah dinilai secara analitis dan uji kaji. Keputusan menunjukkan bahawa di bawah semua peringkat konsistensi, ABMMCCS telah mengurangkan secara signifikan overhead pelanggan mobil dan pelayan asas dan mencapai penggunaan yang lebih baik terhadap rangkaian lebar jalur tanpa wayar berbanding dengan skim Protokol Konsistensi Cache Pelbagai Peringkat (MCCP). Keputusan juga mencerminkan kadar yang tinggi dalam penjimatan lebar jalur *uplink* yang dicapai apabila menggunakan AD-ABMMCCS.

## ACKNOWLEDGEMENTS

I sincerely thank Allah, my God, the Most Gracious, and Most Merciful for enabling me to complete my Ph.D.

I wish to extend my deep thanks gratitude and appreciation to everyone contributed to the successful completion of my thesis. First and foremost, I would like to express my sincere thanks, gratitude, and deep appreciation to my wonderful supervisor Associate Prof. Dr. Hamidah Ibrahim who gave me constant motivation, excellent guidance, insights, and supports during my Ph.D. I extremely grateful and indebted my supervisory committee members Associate Prof. Dr. Ali Mamat and Prof. Dr. Mohamed Othman for their excellent supervision, intellectual guidance and invaluable comments, without which it would have been impossible to complete my dissertation.

I delighted to gratefully acknowledge the Faculty of Mathematical Science, University of Khartoum, and Ministry of higher Education, Sudan for both giving me the opportunity to complete my study and their financial support during my Ph.D. I also extend my thanks to staff members of the Faculty of Computer Science and Information Technology, Universiti Putra Malaysia for their valuable help and their effort to provide facilities, equipments, and an excellent environment to accomplish this research.



Last but not least, no words are ever sufficient to express my everlasting gratitude, appreciation and thanks to my beloved, wonderful mother Suad for being the light in my life. Without her warm love, care, sincere prayers and support, it would have been impossible for me to be myself and to continue learning. I feel extremely indebted and grateful to her for inspiring and illuminating me, and I deeply appreciate her unlimited and incredible support, especially during my stay away from home. I owe an impressive debt and feel unable to sufficiently thank my beloved, wonderful family members in Sudan, Saudi Arabia Kingdom, and United Kingdom, my friends in Sudan and Malaysia they have been real motivation behind the completion of my thesis and success throughout my life.

My sincere thanks. May ALLAH bless and bring pleasure and prosperity to all of you.

*Doha*

I certify that a Thesis Examination Committee has met on 16 January 2012 to conduct the final examination of Doha Elsharief Mahmoud Yagoub on her thesis entitled "Multi-Level Mobile Cache Consistency Schemes Based On Application Requirements" in accordance with Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Doctor of Philosophy

Members of the Thesis Examination Committee were as follows:

**Abdul Azim Abd Ghani, PhD**

Professor

Faculty of Computer Science and Information Technology

Universiti Putra Malaysia

(Chairman)

**Zuriati bt Ahmad Zukarnain, PhD**

Associate Professor

Faculty of Computer Science and Information Technology

Universiti Putra Malaysia

(Internal Examiner)

**Lilly Suriani Affendey, PhD**

Senior Lecturer

Faculty of Computer Science and Information Technology

Universiti Putra Malaysia

(Internal Examiner)

**Xiaofang Zhou, PhD**

Professor

The University of Queensland

(External Examiner)

---

**SEOW HENG FONG, PhD**

Professor and Deputy Dean

School of Graduate Studies

Universiti Putra Malaysia

Date:

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfillment of the requirement for the degree Doctor of Philosophy. The members of the Supervisory Committee were as follows:

**Hamidah Ibrahim, PhD**

Associate Professor  
Faculty of Computer Science and Information Technology  
Universiti Putra Malaysia  
(Chairman)

**Ali Mamat, PhD**

Associate Professor  
Faculty of Computer Science and Information Technology  
Universiti Putra Malaysia  
(Member)

**Mohamed Othman, PhD**

Professor  
Faculty of Computer Science and Information Technology  
Universiti Putra Malaysia  
(Member)

---

**BUJANG BIN KIM HUAN, PhD**

Professor and Dean  
School of Graduate Studies  
Universiti Putra Malaysia  
Date:

## DECLARATION

I declare that the thesis is my original work except for quotations and citations which have been duly acknowledge. I also declare that it has not been previously and is not concurrently, submitted for any other degree at Universiti Putra Malaysia or at any other institution.

---

**DOHA ELSHARIEF MAHMOUD YAGOUB**

Date: 16 January 2012.



## TABLE OF CONTENTS

	Page
<b>DEDICATION</b>	<b>ii</b>
<b>ABSTRACT</b>	<b>iii</b>
<b>ABSTRAK</b>	<b>v</b>
<b>ACKNOWLEDGEMENTS</b>	<b>vii</b>
<b>APPROVAL</b>	<b>ix</b>
<b>DECLARATION</b>	<b>xi</b>
<b>LIST OF TABLES</b>	<b>xv</b>
<b>LIST OF FIGURES</b>	<b>xvi</b>
<b>LIST OF ABBREVIATIONS</b>	<b>xix</b>
<b>CHAPTER</b>	
<b>1 INTRODUCTION</b>	<b>1</b>
1.1 Overview	1
1.2 Problem Statement	2
1.3 Resarch Objectives	4
1.4 Research Scope	5
1.5 Contributions	6
1.6 Organization of the Thesis	7
<b>2 BACKGROUND</b>	<b>9</b>
2.1 Overview	9
2.2 Mobile Network Communication Model	9
2.3 Limitations of Mobile Environment	10
2.4 Caching in Mobile Environment	11
2.5 Cache Consistency Approaches in Distributed Systems	12
2.6 Cache Consistency Approaches in Conventional Client Server	12
2.7 Mobile Cache Consistency Strategies	13
2.8 Stateful and Stateless Approaches	15
2.9 Summary	17
<b>3 LITERATURE REVIEW</b>	<b>18</b>
3.1 Overview	18
3.2 Single-Level Cache Consistency Schemes	18
3.2.1 Stateless Approach Based Schemes	19
3.2.2 Stateful Approach Based Schemes	25
3.2.3 Hybrid Approach	28
3.3 Multi-Level Cache Consistency Schemes	29
3.3.1 Locking the Cached Data Items	29

3.3.2 Consistency Requirements on the Cached Data	30
3.3.3 Maintaining Cache Consistency and Updates Propagation	31
3.4 Summary	32
<b>4 RESEARCH METHODOLOGY</b>	<b>35</b>
4.1 Overview	35
4.2 Analyzing Research Requirements	37
4.2.1 Understanding the Mobile Network Communication Model	37
4.2.2 Recognizing the Performance Metrics	37
4.2.3 Identifying the Implementation Techniques	40
4.3 Designing the Proposed Schemes	41
4.3.1 Features of the Proposed Schemes	41
4.3.2 System Components and Functions	44
4.3.3 AD-ABMMCCS System Components and Functions	46
4.4 Implementing the Schemes	47
4.4.1 Analytical Modeling	47
4.4.2 Analytical Symbol Notations	48
4.4.3 Simulation Modeling	48
4.5 Measuring the Performance of the Proposed Schemes	53
4.6 Evaluating, Comparing and Interpreting the Results	54
4.7 Summary	54
<b>5 MULTI-LEVEL MOBILE CACHE CONSISTENCY SCHEMES BASED ON APPLICATION REQUIREMENTS</b>	<b>55</b>
5.1 Overview	55
5.2 Application Based Multi-level Mobile Cache Consistency Scheme (ABMMCCS)	56
5.2.1 Application Data Consistency Requirements	57
5.2.2 Data Access Control	61
5.2.3 Maintaining Data Consistency and Update Propagation	68
5.2.4 Mobile Cache Validation	72
5.2.5 Messages Exchange	73
5.2.6 Algorithm of the ABMMCCS System Model	73
5.3 An Adaptive Dynamic Application Based Multi-level Mobile Cache Consistency Scheme (AD-ABMMCCS)	78
5.3.1 Characteristics of AD-ABMMCCS	79
5.3.2 System Threshold Value	79
5.3.3 Converting from ABMMCCS to SBT	80
5.3.4 Stateless Broadcasting Technique (SBT)	81
5.3.5 Converting from SBT to ABMMCCS	90
5.4 Summary	90
<b>6 ANALYTICAL MODELING</b>	<b>91</b>
6.1 Overview	91
6.2 Selecting a Data Item for a Query Request	92
6.3 Classifying Client Requests Based on the Lock Types	92

6.4 Average Number of Cache Queries, Lock Requests and Uplink Bandwidth Consumption	94
6.5 Average Number of Accepted Lock Requests	97
6.6 Average Number of Notification Request Messages and Uplink Bandwidth Consumption	102
6.7 Average Number of Update Messages and Uplink Bandwidth Consumption	103
6.8 Average Number of Acknowledgment Messages, Number of UNMs, and Uplink Bandwidth Consumption	107
6.9 Average Number of End Messages and Uplink Bandwidth Consumption	118
6.10 Summary	120
<b>7 RESULTS AND DISCUSSION</b>	<b>121</b>
7.1 Overview	121
7.2 Performance Metrics in MCCP Scheme	121
7.2.1 Completed and Rejected Operations	121
7.2.2 System Throughput	125
7.2.3 Average Number of UNMs Received by Mobile Client	126
7.2.4 Discussion	128
7.3 Mobile Client Overhead	129
7.3.1 Average Number of Uplink and Downlink Messages	130
7.3.2 Discussion	134
7.4 Average Uplink Channel Bandwidth Consumption	135
7.5 Base Server Overhead	136
7.5.1 Average Number of UNMs Propagated from Base Server	137
7.5.2 Discussion	142
7.6 The Impact of AD-ABMMCCS in the Efficiency of ABMMCCS	142
7.7 Summary	146
<b>8 SUMMARY, GENERAL CONCLUSION AND RECOMMENDATIONS FOR FUTURE RESEARCH</b>	<b>147</b>
<b>REFERENCES</b>	<b>151</b>
<b>APPENDICES</b>	<b>157</b>
<b>BIODATA OF STUDENT</b>	<b>164</b>
<b>LIST OF PUBLICATIONS</b>	<b>165</b>