The copyright © of this thesis belongs to its rightful author and/or other copyright owner. Copies can be accessed and downloaded for non-commercial or learning purposes without any charge and permission. The thesis cannot be reproduced or quoted as a whole without the permission from its rightful owner. No alteration or changes in format is allowed without permission from its rightful owner.

AN ADAPTIVE TRUST BASED SERVICE QUALITY MONITORING MECHANISM FOR CLOUD COMPUTING

MOHAMED FAZIL MOHAMED FIRDHOUS

Universiti Utara Malaysia

DOCTOR OF PHILOSOPHY
UNIVERSITI UTARA MALAYSIA
2016

Permission to Use

In presenting this thesis in fulfillment of the requirements for a postgraduate degree from Universiti Utara Malaysia, I agree that the University Library may make it freely available for inspection. I further agree that permission for the copying of this thesis in any manner, in whole or in part, for scholarly purpose may be granted by my supervisor(s) or, in their absence, by the Dean of Awang Had Salleh Graduate School of Arts and Sciences. It is understood that any copying or publication or use of this thesis or parts thereof for financial gain shall not be allowed without my written permission. It is also understood that due recognition shall be given to me and to Universiti Utara Malaysia for any scholarly use which may be made of any material from my thesis.

Requests for permission to copy or to make other use of materials in this thesis, in whole or in part, should be addressed to:

Universiti Utara Malaysia

Dean of Awang Had Salleh Graduate School of Arts and Sciences
UUM College of Arts and Sciences
Universiti Utara Malaysia
06010 UUM Sintok

Abstrak

Pengkomputeran awan adalah paradigma terkini dalam pengkomputeran teragih yang menyediakan sumber pengkomputeran melalui Internet sebagai perkhidmatan. Oleh kerana daya tarikan pengkomputeran awan, pasaran kini dibanjiri oleh ramai pembekal perkhidmatan. Ini mewujudkan keperluan pelanggan untuk mengenal pasti pembekal perkhidmatan yang betul, yang akan memenuhi keperluan mereka dari segi kualiti perkhidmatan. Pemantauan kualiti perkhidmatan pengkomputeran awan sedia ada hanya terhad kepada pengukuran sahaja. Sebaliknya, peningkatan berterusan dan taburan skor kualiti perkhidmatan telah dilaksanakan dalam paradigma pengkomputeran teragih tetapi tidak khusus untuk pengkomputeran awan. Penyelidikan ini mengkaji kaedah-kaedah serta mencadangkan mekanisma untuk mengukur dan menentukan kedudukan kualiti perkhidmatan pembekal perkhidmatan. Penyelesaian yang dicadangkan dalam tesis ini terdiri daripada tiga mekanisma iaitu mekanisma perkhidmatan pemodelan kualiti, mekanisma pengkomputeran penyesuaian kepercayaan dan mekanisma pengedaran kepercayaan bagi pengkomputeran awan. Kaedah Penyelidikan Rekabentuk (KPR) telah diubah suai dengan menambah fasa, cara dan kaedah, dan hasil kemungkinan. KPR yang diubahsuai ini telah digunakan sepanjang kajian ini. Mekanisma ini telah dibangunkan dan diuji secara beransur-ansur sehingga mencapai hasil yang diharapkan. Satu set eksperimen yang menyeluruh telah dijalankan dalam persekitaran simulasi untuk mengesahkan keberkesanannya. Penilaian telah dijalankan dengan membandingkan prestasi mereka dengan gabungan model kepercayaan dan model kepercayaan QoS bersama-sama dengan mekanisma pengiraan kepercayaan berasaskan teori logik fuzi dan mekanisma pengagihan kepercayaan berasaskan konsep agen utama yang telah dibangunkan untuk sistem teragih lain. Keputusan menunjukkan mekanisma yang dicadangkan dalam tesis ini adalah lebih pantas dan stabil berbanding mekanisma sedia ada dalam mencapai skor kepercayaan akhir menggunakan kriteria yang diuji. Keputusan yang dibentangkan dalam tesis ini adalah penting dalam usaha untuk membolehkan pengguna mengesahkan prestasi pembekal perkhidmatan sebelum membuat pilihan yang tepat.

Kata kunci: Pengkomputeran awan, Pemantauan kualiti perkhidmatan, Pengkuantitian kualiti perkhidmatan, Pengkomputeran kepercayaan, Pengagihan kepercayaan

Abstract

Cloud computing is the newest paradigm in distributed computing that delivers computing resources over the Internet as services. Due to the attractiveness of cloud computing, the market is currently flooded with many service providers. This has necessitated the customers to identify the right one meeting their requirements in terms of service quality. The existing monitoring of service quality has been limited only to quantification in cloud computing. On the other hand, the continuous improvement and distribution of service quality scores have been implemented in other distributed computing paradigms but not specifically for cloud computing. This research investigates the methods and proposes mechanisms for quantifying and ranking the service quality of service providers. The solution proposed in this thesis consists of three mechanisms, namely service quality modeling mechanism, adaptive trust computing mechanism and trust distribution mechanism for cloud computing. The Design Research Methodology (DRM) has been modified by adding phases, means and methods, and probable outcomes. This modified DRM is used throughout this study. The mechanisms were developed and tested gradually until the expected outcome has been achieved. A comprehensive set of experiments were carried out in a simulated environment to validate their effectiveness. The evaluation has been carried out by comparing their performance against the combined trust model and QoS trust model for cloud computing along with the adapted fuzzy theory based trust computing mechanism and super-agent based trust distribution mechanism, which were developed for other distributed systems. The results show that the mechanisms are faster and more stable than the existing solutions in terms of reaching the final trust scores on all three parameters tested. The results presented in this thesis are significant in terms of making cloud computing acceptable to users in verifying the performance of the service providers before making the selection.

Universiti Utara Malaysia

Keywords: Cloud computing, Service quality monitoring, Service quality quantification, Trust computing, Trust distribution

Declaration

Some of the works presented in this thesis have been published or submitted as listed below.

Book Chapters

[1] **Mohamed Firdhous**, Suhaidi Hassan, Osman Ghazali and Massudi Mahmuddin, "Evaluating Cloud System Providers: Models, Methods and Applications" in "Cloud Systems in Supply Chains" Chapter 7, Dr. Fawzy Soliman, Ed. (pp. 121-149). Basingstoke, Hampshire, UK: Palgrave Macmillan, 2014 (ISBN – 978-1-13-732425-2).

Journal Articles

[2] **Mohamed Firdhous**, Osman Ghazali, and Suhaidi Hassan, "A Mechanism for Distribution and Sharing of Trust Scores among Cooperating Cloud Computing Service Monitors", Accepted for publication in Jurnal Teknologi (Sciences & Engineering) (Special Issue on Current and Emerging Trends in Technology, Science and Engineering), Scopus Indexed. (Won the best paper award at the Second AFAP Conference on Current and Emerging Trends in Science and Engineering, Surabaya, Indonesia 13/09/2014)

[3] **Mohamed Firdhous**, Osman Ghazali, and Suhaidi Hassan, "Modeling of Quality of Service based Trust for Cloud Computing", Accepted for publication in Jurnal Teknologi (Sciences & Engineering) (Special Issue on Current and Emerging Trends in Technology, Science and Engineering), Scopus Indexed.

[4] **Mohamed Firdhous**, Osman Ghazali, and Suhaidi Hassan, "Robust Multi-Dimen-sional Trust Computing Mechanism for Cloud Computing", Jurnal Teknologi (Sciences & Engineering) (Special Issue on Current and Emerging Trends in

Universiti Utara Malaysia

Technology, Science and Engineering Vol. 2), vol. 69, no. 2, July 2014, pp. 1-6. Scopus Indexed.

[5] **Mohamed Firdhous**, Osman Ghazali, and Suhaidi Hassan, "Statistically Controlled Robust Trust Computing Mechanism for Cloud Computing", Journal of Information and Communication Technology (JICT), vol. 13, 2014, pp. 23-39. Scopus Indexed.

[6] **Mohamed Firdhous**, Suhaidi Hassan and Osman Ghazali, "Monitoring, Tracking and Quantification of Quality of Service in Cloud Computing", International Journal of Scientific & Engineering Research (IJSER), vol. 04, no. 05, May, 2013, pp. 112 – 117.

[7] **Mohamed Firdhous**, Suhaidi Hassan and Osman Ghazali, "A Comprehensive Survey on Quality of Service Implementations in Cloud Computing", International Journal of Scientific & Engineering Research (IJSER), vol. 04, no. 05, May, 2013, pp. 118 – 123.

Universiti Utara Malaysia

[8] **Mohamed Firdhous**, Suhaidi Hassan and Osman Ghazali, "Statistically Enhanced Multi-Dimensional Trust Computing Mechanism for Cloud Computing", Journal of Mobile Computing and Multimedia Communications (IJMCMC), vol. 05, no. 02, April-June, 2013, pp. 1 – 17. Scopus Indexed.

[9] **Mohamed Firdhous**, Osman Ghazali, and Suhaidi Hassan, "Trust Management in Cloud Computing – A Critical Review", International Journal on Advances in ICT for Emerging Regions (ICTer), vol. 04, no. 02, Sept. 2011, pp. 24 – 36.

Conference Papers

[10] **Mohamed Firdhous**, Suhaidi Hassan and Osman Ghazali, "Monitoring, Tracking and Quantification of Quality of Service in Cloud Computing" 3rd Global Conference for Academic Research on Scientific and Emerging Technologies (GCARSET), March 9–11, 2013, Kuala Lumpur, Malaysia, pp. 107-112.

[11] **Mohamed Firdhous**, Suhaidi Hassan and Osman Ghazali, "Quality of Service in Cloud Computing – A Critical Review" 3rd Global Conference for Academic Research on Scientific and Emerging Technologies (GCARSET), March 9–11, 2013, Kuala Lumpur, Malaysia, pp. 113-118.

[12] **Mohamed Firdhous**, Suhaidi Hassan and Osman Ghazali, "Hysteresis based Trust Computing Mechanism for Cloud Computing" 2012 IEEE Region 10 Conference (TENCON 2012), November 19–22, 2012, Cebu, Philippines, pp. 796-801.

[13] **Mohamed Firdhous**, Suhaidi Hassan, Osman Ghazali, and Massudi Mahmuddin, "Bio Inspired Trust Management in Distributed Systems - A Critical Review", 2012 IEEE Conference on Open Systems (ICOS2012), October 21-24, 2012, Kuala Lumpur, Malaysia,

[14] **Mohamed Firdhous**, Suhaidi Hassan and Osman Ghazali, "Multi-Dimensional Trust Computing Mechanism for Cloud Computing" 3rd International Conference on Network Applications, protocols and services (NetApps 2012), September 19-20, 2012, Sintok, Kedah Darul Aman, Malaysia, pp. 7-12.

[15] **Mohamed Firdhous**, Osman Ghazali, and Suhaidi Hassan, "A Memoryless Trust Computing Mechanism for Cloud Computing", The Fourth International Conference on Networked Digital Technologies (NDT'2012), April 24-26, 2012- Dubai, UAE, pp.174-185, published in Communications in Computer and Information Science, R.

Benlamri, Ed., Berlin Heidelberg, Germany: Springer-Verlag, 2012, Vol. 293, pp. 174–185. DOI: 10.1007/978-3-642-30507-8.

[16] **Mohamed Firdhous**, Osman Ghazali, and Suhaidi Hassan, "Applying Bees Algorithm for Trust Management in Cloud Computing", 6th International ICST Conference on Bio-Inspired Models of Network, Information, and Computing Systems (BIONETICS 2011), December 5th - 7th, 2011 - York, England, published in Lecture Notes on ICST (LNICST) E. Hart et al. Eds., Berlin Heidelberg, Germany: Springer-Verlag, 2012, Vol. 103, pp. 224–229.

[17] **Mohamed Firdhous**, Osman Ghazali, and Suhaidi Hassan, "A trust computing mechanism for cloud computing with multilevel thresholding", Sixth IEEE International Conference on Industrial & Information Systems (ICIIS2011), August 16-19, 2011, Kandy, Sri Lanka, pp. 457-461.

[18] **Mohamed Firdhous**, Osman Ghazali, and Suhaidi Hassan, "A trust computing mechanism for cloud computing", 4th ITU Kaleidoscope Academic Conference, December 12–14, 2011, Cape Town, South Africa, pp. 199-205.

[19] **Mohamed Firdhous**, Osman Ghazali, Suhaidi Hassan, "Modeling of cloud system using Erlang formulas", 17th Asia-Pacific Conference on Communications, October 3-5, 2011, Kota Kinabalu, Sabah, Malaysia, pp. 411-416.

[20] **Mohamed Firdhous**, Osman Ghazali, Suhaidi Hassan, Nur Ziadah Harun and Azizi Abas, “Honey Bee Based Trust Management System for Cloud Computing”, 3rd International Conference on Computing and Informatics (ICOCI2011), June 8-9, 2011 Bandung, Indonesia, pp. 327-332.

Universiti Utara Malaysia

Acknowledgments

In the name of Allah the Most Beneficent, the Most Merciful.

Studying towards a PhD, though it is very rewarding at the end, it is a very tedious and challenging journey. I have almost reached the end of it with a lot of effort, blood, sweat and tears. There are several people, who helped to reach this stage successfully. I will fail in my duty, if I do not give them the credit that is rightfully due to them.

First and foremost, I must thank my supervisors Prof. Madya Dr. Osman Ghazali and Prof. Dr. Suhaidi Hassan. It has been an honor to be a PhD student under them. I really appreciate all their contributions in terms of advice, support, time and ideas that made my PhD experience productive and stimulating. A special thanks for encouraging me to write research articles and proceeding papers that helped me a lot in improving my language skills and would go a long way in my career development as an academic.

I would like to extend my sincere gratitude to my former vice chancellor Prof. Malik Ranasnghe at the University of Moratuwa, Sri Lanka. He not only encouraged me to start my PhD, but also give the list of people who I should approach along with a strong recommendation letter. He also approved my study leave at the shortest possible time.

Then I would like to thank my InterNetWoks research laboratory members both the academic staff and students. They kept the environment very nice and stimulating throughout my stay there.

Finally I would extend my gratitude to my family especially my wife Shamila. I really appreciate her understanding and support. I really have to mention my daughter Fathima Sameeha and son Mohamed Shabaz, though they missed me a lot during this period, they gave me the reason and courage that I should finish this journey successfully.

Universiti Utara Malaysia

Table of Contents

Permission to Use ii

Abstrak iii

Abstract iv

Declaration v

Acknowledgments ix

Table of Contents x

List of Tables xiv

List of Figures xv

List of Abbreviations xviii

CHAPTER ONE OVERVIEW 1

1.1 Introduction 1

1.2 Background 1

1.2.1 Cloud Computing 2

1.3 Problems and Issues Pertaining to Cloud Computing 5

1.4 Research Motivation 7

1.5 Problem Statement 9

1.6 Research Questions 11

1.7 Research Objectives 11

1.8 Research Scope 12

1.9 Significance of the Research and Expected Contributions 13

1.10 Organization of the Thesis 14

CHAPTER TWO LITERATURE REVIEW 16

2.1 Introduction 16

2.2 Cloud Computing 16

2.2.1 Cloud Computing Service Offerings 18

2.2.2 Cloud Computing Deployment Models 21

2.3 Quality of Service in Cloud Computing 27

2.3.1 Service Quality Monitoring in Cloud Computing 34

Universiti Utara Malaysia

2.3.2 Service Quality Parameters in Cloud Computing 39
2.3.3 Definition of Performance Metrics 42
2.4 Trust Computing and Management 44
2.4.1 Trust Management in Cloud Computing 48
2.5 Summary 61

CHAPTER THREE RESEARCH METHODOLOGY 62
3.1 Introduction 62
3.2 Research Approach 64
3.2.1 Analysis 66
3.3 Design 70
3.3.1 Model Development 72
3.3.2 Model Implementation 73
3.3.3 Model Validation 74
3.4 Testing 76
3.5 Evaluation 79
3.5.1 Selecting the Evaluation Approach 79
3.5.2 CloudSim Simulation Suite 86
3.5.3 Experiment Environment 90
3.6 Summary 97

CHAPTER FOUR SERVICE QUALITY MODELING MECHANISM FOR CLOUD COMPUTING 99
4.1 Introduction 99
4.2 Normalizing of Performance Metrics 100
4.3 Modeling of Service Quality of Cloud Providers 103
4.3.1 Single Parameter Service Quality Quantification Mechanism (SP-SQQM) 104
4.4 Multi-Parameter Service Quality Quantification Mechanism (MP-SQQM) 107
4.4.1 Computing Trust Score with Different Priorities 111
4.5 Functional Verification of MP-SQQM 112
4.6 Summary 115

Universiti Utara Malaysia

CHAPTER FIVE ADAPTIVE TRUST COMPUTING MECHANISM FOR CLOUD COMPUTING 116

5.1 Introduction 116

5.2 Trust Formation and Evolution 117

5.3 Adaptive Continuous Trust Evolution Mechanism (ACTEM) 118

5.3.1 Functional Verification of ACTEM 120

5.4 Memoryless Trust Computing Mechanism (MemTrust) 122

5.4.1 Functional Verification of MemTrust 125

5.5 Hysteresis-based Trust Evolution Mechanism (HystTrust) 127

5.5.1 Hysteresis Function 129

5.5.2 Pseudo Code of the Proposed Algorithm 130

5.5.3 Functional Verification of HystTrust 130

5.6 Robust Adaptive Trust Computing Mechanism (RATComM) 132

5.6.1 Functional Evaluation of RATComM 133

5.7 Multi-Dimensional Trust Computing Mechanism (MuDTComM) 136

5.7.1 Functional Evaluation of MuDTComM 139

5.8 Summary 140

CHAPTER SIX PROBABILITY-BASED TRUST DISTRIBUTION MECHANISM FOR CLOUD COMPUTING 141

6.1 Introduction 141

6.2 Distribution of Trust Scores 142

6.2.1 Trust Table Updating Process 144

6.3 Probability-based Trust Distribution Mechanism (PTDiMech) 146

6.3.1 Functional Evaluation of PTDiMech 150

6.4 Summary 151

CHAPTER SEVEN PERFORMANCE ANALYSIS OF TRUST COMPUTING AND DISTRIBUTION MECHANISMS 153

7.1 Introduction 153

7.2 Simulation Environment 153

7.3 Performance Analysis of Service Quality Quantification Mechanisms . . . 156

7.3.1 Performance Analysis of SP-SQQM 157

7.3.2 Performance Analysis of MP-SQQM 160
7.4 Performance Analysis of Trust Computing Mechanisms 162
7.4.1 Performance Analysis of Adaptive Continuous Trust Evolution Mechanism 164
7.4.2 Performance Analysis of MemTrust 167
7.4.3 Performance Analysis of HystTrust 168
7.4.4 Performance Analysis of RATComM 170
7.4.5 Performance Analysis of MuDTComM 171
7.5 Performance Analysis of Trust Distribution Mechanism 173
7.6 Summary 179

CHAPTER EIGHT CONCLUSIONS AND FUTURE WORK 182
8.1 Introduction 182
8.2 Summary of Research 182
8.3 Research Contributions 185
8.4 Research Limitations 186
8.5 Recommendations for Future Work 187

REFERENCES 189

Universiti Utara Malaysia

List of Tables

Table 2.1 Summary of Features of the Service Quality Monitoring Mechanisms 37
Table 2.2 Summary of Trust Computing Mechanisms for Cloud Computing . 58

Table 3.1 Comparison of Different Evaluation Approaches 80
Table 3.2 Comparison of Different Cloud Simulators 86
Table 3.3 Virtual Machine Mapping 93
Table 3.4 Experiment Setup Attributes and Values 94

Table 4.1 Performance Table 110
Table 4.2 Modified Performance Table 112

Table 6.1 Sample Trust Table 146
Table 6.2 Conditional Probability Table at N_S for N_D 149

Table 7.1 Specification of the Host Computer 154
Table 7.2 Experiment Setup Attributes for the Evaluation of SQQMs 156
Table 7.3 Service Quality Requirements for Service Quality Quantification Mechanisms 156
Table 7.4 Experiment Setup Attributes for the Evaluation of Trust Computing Mechanisms 163
Table 7.5 Service Quality Requirements for Trust Computing Mechanisms . . 163
Table 7.6 Experiment Setup Attributes for the Evaluation of Trust Distribution Mechanism 173
Table 7.7 Service Quality Requirements for Trust Distribution Mechanism . . 174

Universiti Utara Malaysia

List of Figures

Figure 1.1 Capacity Utilization Curve 3

Figure 2.1 Cloud Computing Service Offerings 19
Figure 2.2 Cloud Computing Deployment Models 22

Figure 3.1 Research Methodology 63
Figure 3.2 Stages of Design Research Methodology 64
Figure 3.3 Research Approach 66
Figure 3.4 Main Steps Involved in Research Clarification Stage 67
Figure 3.5 Main Steps in Descriptive Study - I 69
Figure 3.6 Conceptual Model 70
Figure 3.7 Mechanism Development Process 71
Figure 3.8 Eclipse Integrated Development Environment for Java 77
Figure 3.9 QJ-Pro Code Analysis Window 78
Figure 3.10 CloudSim Layered Architecture 88
Figure 3.11 CloudSim Class Diagram 89
Figure 3.12 Simulation Steps 91

Figure 4.1 Change in Trust Scores 105
Figure 4.2 Comparative Change in Trust Scores 106
Figure 4.3 Naive Bayesian Network 109
Figure 4.4 Naive Bayesian Network for a Cloud Computing System 109
Figure 4.5 Trust Score Computed Using Two Input Parameters 113
Figure 4.6 Effect of Weights on Trust Scores Computed 114
Figure 4.7 Effect of Weights on Final Trust Score 114

Figure 5.1 Trust Management System 119
Figure 5.2 Trust Scores due to Continuous Positive or Negative Feedbacks . . 121
Figure 5.3 Effect of Confidence Level on Trust Scores Computed 121
Figure 5.4 MemTrust Trust Evolution Unit 122
Figure 5.5 Sigmoid Function 124

Universiti Utara Malaysia

Figure 5.6 Modified Sigmoid Function 125
Figure 5.7 Trust Scores Computed for Constant Positive Responses 126
Figure 5.8 Trust Scores Computed for Constant Negative Responses 126
Figure 5.9 Trust Scores Computed for Random Response Time Requirement . 127
Figure 5.10 MemTrust Trust Evolution Unit 128
Figure 5.11 Sample Hysteresis Curve 129
Figure 5.12 Comparison of Trust for Random Response Times 132
Figure 5.13 RATComM Trust Evolution Unit 133
Figure 5.14 Trust Scores with 90% Validated Inputs Vs. Non Validated Inputs . 135
Figure 5.15 Trust Scores with 95% Validated Inputs Vs. Non Validated Inputs . 135
Figure 5.16 Effect of Confidence Level on Trust Scores 136
Figure 5.17 MuDTComM Trust Evolution Unit 137
Figure 5.18 MuDTComM Trust Evolution Unit in Detail 137
Figure 5.19 Comparison of RATComM and MuDTComM Trust Evolution Units 139
Figure 5.20 The Effect of Weights and Confidence Level on Trust Scores . . . 140

Figure 6.1 High-Level Architecture of Trust Distribution System 143
Figure 6.2 Trust Administration Unit 144
Figure 6.3 Trust Updating Process 145
Figure 6.4 Bayesian Network for Node *NS* 148
Figure 6.5 Change of Trust Scores for CSP_1 over a Period of Time 151

Figure 7.1 Eclipse IDE Loaded with CloudSim 154
Figure 7.2 A Typical CloudSim Life Cycle 155
Figure 7.3 SP-SQQM: Trust Scores Computed Using Response Time 158
Figure 7.4 SP-SQQM: Trust Scores Computed Using Service Time 159
Figure 7.5 SP-SQQM: Trust Scores Computed Using Availability 159
Figure 7.6 MP-SQQM: Trust Scores with Equal Weights 160
Figure 7.7 MP-SQQM: Trust Scores with Unequal Weights (Case I) 161
Figure 7.8 MP=SQQM: Trust Scores with Unequal Weights (Case II) 161
Figure 7.9 ACTEM: Trust Scores Computed based on Response Time 165
Figure 7.10 ACTEM: Trust Scores Computed based on Service Time 166
Figure 7.11 ACTEM: Trust Scores Computed based on Availability 166

Universiti Utara Malaysia

Figure 7.12 MemTrust: Trust Scores Computed based on Response Time . . . 167
Figure 7.13 MemTrust: Trust Scores Computed based on Service Time 167
Figure 7.14 MemTrust: Trust Scores Computed based on Availability 168
Figure 7.15 HystTrust: Trust Scores Computed based on Response Time . . . 169
Figure 7.16 HystTrust: Trust Scores Computed based on Service Time 169
Figure 7.17 HystTrust: Trust Scores Computed based on Availability 169
Figure 7.18 RATComM: Trust Scores Computed based on Response Time . . . 170
Figure 7.19 RATComM: Trust Scores Computed based on Service Time 170
Figure 7.20 RATComM: Trust Scores Computed based on Availability 171
Figure 7.21 Trust Scores Computed by MuDTComM and Fuzzy Mechanisms . 172
Figure 7.22 Effect of Weights on Trust Scores - MuDTComM vs Fuzzy 172
Figure 7.23 PTDiMech: Trust Scores Computed based on Response Time . . . 176
Figure 7.24 PTDiMech: Trust Scores Computed based on Service Time 177
Figure 7.25 PTDiMech: Trust Scores Computed based on Availability 178
Figure 7.26 PTDiMech: Trust Scores Computed with Equal Weights 178
Figure 7.27 PTDiMech: Trust Scores Computed with Different Weights 179

Universiti Utara Malaysia

List of Abbreviations

ACTEM	Adaptive Continuous Trust Evolution Mechanism
API	Application Programming Interface
AWS	Amazon Web Services
CDO	Cloud Deployment Options
CSP	Cloud Service Provider
DRM	Design Research Methodology
DS-I	Descriptive Study I
DS-II	Descriptive Study II
FBCT	Family-gene Based model for Cloud Trust
FIFO	First In First Out
GUT	Graphical User interface
HystTrust	Hysteresis-based Trust Evolution Mechanism
IaaS	Infrastructure as a Service
IdP	Identity Policy
IdPS	Identity Practice Statement
IDE	Integrated Development Environment
ISO	International Standards Organization
JVM	Java Virtual Machine
KPI	Key Performance Indicators
MemTrust	Memoryless Trust Computing Mechanism
MP-SQQM	Multi-Parameter Service Quality Quantification Mechanism
MTCEM	Multi-tenancy Trusted Computing Environment Model
MuDTComM	Multi-Dimensional Trust Computing Mechanism
PaaS	Platform as a Service
PERMIS	PrivilEge and Role Management Infrastructure Standard
PS	Prescriptive Study
PSO	Particle Swarm Optimization
PTDiMech	Probability-based Trust Distribution Mechanism

Universiti Utara Malaysia

QoE	Quality of Experience
QoS	Quality of Service
RAM	Random Access Memory
RATComM	Robust Adaptive Trust Computing Mechanism
RC	Research Clarification
S3	Simple Storage Service
SaaS	Software as a Service
SLA	Service Level Agreement
SMI	Service Measurement Index
SP	Service Policy
SPS	Service Practice Statement
SP-SQQA	Single Parameter Service Quality Quantification Algorithm
SP-SQQM	Single Parameter Service Quality Quantification Mechanism
TSS	Trusted Platform Software Stack
VM	Virtual Machine
VMM	Virtual Machine Manager

Universiti Utara Malaysia

CHAPTER ONE
OVERVIEW

1.1 Introduction

This chapter presents a brief introduction to the proposed research along with the general background information on cloud computing in brief including its features, advantages, disadvantages and issues. The chapter also outlines the problem statement and research questions, research motivation, research objectives, research scope and the significance of the research along with the contributions. Finally the outline of the proposal is presented at the end.

1.2 Background

Cloud computing has become very popular among the computing community in the recent years. It has already has earned the nickname the 5^{th} *utility* due to its versatile and economic way of making resources available over the Internet [1]. Utilities make the resources available to a wider clientèle and charge them only for the usage. Electricity, water, gas and telephony are the four major utilities that have been commonly used in this manner before the arrival of cloud computing. Prior to the emergence of cloud computing in the latter part of the 1st decade of 2000s, computing resources such as hardware including processor power, storage, networks bandwidth were either purchased outright and installed in the data centers owned and operated by end users themselves or leased from public data centers on fixed monthly or annual charges [2]. The clients installed the operating systems, tools and applications of their choice on these hardware dedicated only for their use. Once the hardware has been purchased or leased in this manner, the capacity of these systems were fixed irrespective of usage. The computing resources thus installed in clients' data centers are generally underutilized. Recent surveys have found that in many data centers the

Universiti Utara Malaysia

The contents of the thesis is for internal user only

REFERENCES

[1] R. Buyya, C. S. Yeo, S. Venugopal, J. Broberg, and I. Brandic, "Cloud computing and emerging IT platforms: Vision, hype, and reality for delivering computing as the 5th utility," *Journal of Future Generation Computer Systems*, vol. 25, no. 6, pp. 599–616, June 2009.

[2] F. Hu, M. Qiu, J. Li, T. Grant, D. Tylor, S. McCaleb, L. Butler, and R. Hamner, "A review on cloud computing: Design challenges in architecture and security," *Journal of Computing and Information Technology*, vol. 19, no. 1, pp. 25–55, 2011.

[3] S. Marston, Z. Li, S. Bandyopadhyay, J. Zhang, and A. Ghalsasi, "Cloud computing - the business perspective," *Decision Support Systems*, vol. 51, no. 1, pp. 176–189, 2011.

[4] J. Jaatmaa, "Financial aspects of cloud computing business models," Master's thesis, School of Economics, Aalto University, Finland, 2010.

[5] S. Islam, K. Lee, A. Fekete, and A. Liu, "How a consumer can measure elasticity for cloud platforms," in *3rd Joint WOSP/SIPEW International Conference on Performance Engineering, Boston, MA, USA*, 2012, pp. 85–96.

[6] AWS. (2012) Capacity utilization curve. AWS Economics Center. - Accessed on 05/01/2012. [Online]. Available: http://aws.amazon.com/economics/

[7] K. Collins, *Exploring Business*. Hoboken, NJ: Prentice Hall, 2007.

[8] K. Rafique, A. W. Tareen, M. Saeed, J. Wu, and S. S. Qureshi, "Cloud computing economics opportunities and challenges," in *4th IEEE International Conference on Broadband Network and Multimedia Technology (IC-BNMT), Shenzhen, China*, 2011, pp. 401–406.

[9] R. M. Sharma, "The impact of virtualization in cloud computing," *International Journal of Recent Development in Engineering and Technology*, vol. 3, no. 1, pp. 197–202, 2014.

[10] S. Zaman and D. Grosu, "Combinatorial auction-based allocation of virtual machine instances in clouds," in *Second IEEE International Conference on Cloud Computing Technology and Science, Indianapolis, IN, USA*, 2010, pp. 127–134.

[11] A. A. Semnanian, J. Pham, B. Englert, and X. Wu, "Virtualization technology and its impact on computer hardware architecture," in *Eighth International Conference on Information Technology: New Generations, Las Vegas, NV, USA*, 2011, pp. 719–724.

[12] R. Y. Ameen and A. Y. Hamo, "Survey of server virtualization," *International Journal of Computer Science and Information Security,*, vol. 11, no. 3, pp. 1–10, 2013.

[13] C. Vecchiola, S. Pandey, and R. Buyya, "High-performance cloud computing: A view of scientific applications," in *10th International Symposium on Pervasive Systems, Algorithms, and Networks (ISPAN), Kaohsiung, Taiwan*, 2009, pp. 4–16.

[14] R. Buyya, A. Beloglazov, and J. Abawajy, "Energy-efficient management of data center resources for cloud computing: A vision, architectural elements, and open challenges," in *International Conference on Parallel and Distributed Processing Techniques and Applications, Las Vegas, NV*, 2010, pp. 6–20.

[15] Y. Li, W. Li, and C. Jiang, "A survey of virtual machine system: Current technology and future trends," in *Third International Symposium on Electronic Commerce and Security, Guangzhou, China*, 2010, pp. 332–336.

[16] A. Apostu, F. Puican, G. Ularu, G. Suciu, and G. Todoran, *Recent Advances in Applied Computer Science and Digital Services*. New York, NY: WSEAS Press, 2013, ch. Study on Advantages and Disadvantages of Cloud Computing - The Advantages of Telemetry Applications in the Cloud, pp. 118–123.

[17] A. Thilakarathne and J. I. Wijayanayake, "Security challenges of cloud computing," *International Journal of Scientific and Technology Research*, vol. 3, no. 11, pp. 200–203, 2014.

[18] A. A. Omotunde, O. Awodele, S. O. Kuyoro, and C. Ajaegbu, "Survey of cloud computing issues at implementation level," *Journal of Emerging Trends in Computing and Information Sciences*, vol. 4, no. 1, pp. 91–96, 2013.

[19] D. C. Marinescu, *Cloud Computing: Theory and Practice*, 1st ed. Morgan Kaufmann, 2013.

[20] A. Iosup, S. Ostermann, M. N. Yigitbasi, R. Prodan, T. Fahringer, and D. H. J. Epema, "Performance analysis of cloud computing services for many-tasks scientific computing," *IEEE Transactions on Parallel and Distributed Systems*, vol. 22, no. 6, pp. 931–945, 2011.

[21] G. Feng, S. Garg, R. Buyya, and W. Li, "Revenue maximization using adaptive resource provisioning in cloud computing environments," in *13th ACM/IEEE International Conference on Grid Computing, Beijing, China*, 2012, pp. 192–200.

[22] *Amazon S3 Service Level Agreement*, accessed on February 07, 2013. [Online]. Available: http://aws.amazon.com/s3-sla/

[23] H. A. Akpan and B. R. J. Vadhanam, "A survey on quality of service in cloud computing," *International Journal of Computer Trends and Technology*, vol. 27, no. 1, pp. 58–63, 2015.

[24] H. Blodget, *Amazon's Cloud Crash Disaster Permanently Destroyed Many Customers' Data*, accessed on February 07, 2013. [Online]. Available: http://www.businessinsider.com/amazon-lost-data-2011-4

Universiti Utara Malaysia

[25] S. P. Ahuja and S. Mani, "Availability of services in the era of cloud computing," *Network and Communication Technologies*, vol. 1, no. 1, pp. 2–6, 2012.

[26] Y. Sun, J. Zhang, Y. Xiong, and G. Zhu, "Data security and privacy in cloud computing," *International Journal of Distributed Sensor Networks*, pp. 1–9, 2014.

[27] K. Xiong and H. Perros, "Service performance and analysis in cloud computing," in *IEEE World Congress on Services, Los Angeles, CA*, 2009, pp. 693–700.

[28] G. Singh and V. K. Sachdeva, "Impact and challenges of cloud computing in current scenario," *International Journal of Social Science & Interdisciplinary Research*, vol. 1, no. 10, pp. 131–144, 2012.

[29] K. Alhamazani, R. Ranjan, P. P. Jayaraman, K. Mitra, C. Liu, F. Rabhi, D. Georgakopoulos, and L. Wang, "Cross-layer multi-cloud real-time application QoS monitoring and Benchmarking As-a-Service framework," *IEEE Transactions on Cloud Computing*, vol. PP, no. 99, pp. 1–13, 2015.

[30] P. A. Salz, "Monitoring mobile application performance," *Journal of Direct, Data and Digital Marketing Practice*, vol. 15, pp. 219–221, 2014.

[31] S. Bosse, C. Schulz, and K. Turowski, "Predicting availability and response times of IT services," in *22nd European Conference on Information Systems, Tel Aviv, Israel*, 2014, pp. 1–14.

[32] S. K. Garg, S. Versteeg, and R. Buyya, "A framework for ranking of cloud computing services," *Future Generation Computer Systems*, vol. 29, pp. 1012–1023, 2013.

[33] J. S. Ward and A. Barker, "Observing the clouds: A survey and taxonomy of cloud monitoring," *Journal of Cloud Computing: Advances, Systems and Applications*, vol. 3, no. 24, pp. 1–30, 2014.

[34] M. H. Mohamaddiah, A. Abdullah, S. Subramaniam, and M. Hussin, "A survey on resource allocation and monitoring in cloud computing," *International Journal of Machine Learning and Computing, Vol. 4, No. 1, February 2014*, vol. 4, no. 1, pp. 31–38, 2014.

[35] A. Brinkmann, C. Fiehe, A. Litvina, I. Luck, L. Nagel, K. Narayanan, F. Ostermair, and W. Thronicke, "Scalable monitoring system for clouds," *IEEE/ACM 6th International Conference on Utility and Cloud Computing, Dresden, Germany*, pp. 351–356, 2013.

[36] S. Suakanto, S. H. Supangkat, Suhardi, and R. Saragih, "Performance measurement of cloud computing services," *International Journal on Cloud Computing: Services and Architecture*, vol. 2, no. 2, pp. 9–20, 2012.

[37] G. Aceto, A. Botta, W. de Donato, and A. Pescape, "Cloud monitoring: Definitions, issues and future directions," *1st IEEE International Conference on Cloud Networking,Paris, France*, pp. 63–67, 2012.

Universiti Utara Malaysia

[38] R. Buyya, S. K. Garg, and R. N. Calheiros, "SLA-oriented resource provisioning for cloud computing: Challenges, architecture, and solutions," in *International Conference on Cloud and Service Computing, Hong Kong*, 2011, pp. 1–10.

[39] W. N. Chen and J. Zhang, "A set-based discrete pso for cloud workflow scheduling with user-defined qos constraints," in *IEEE International Conference on Systems, Man and Cybernetics, Seoul, Korea*, 2012, pp. 773–778.

[40] R. V. den Bossche, K. Vanmechelen, and J. Broeckhove, "Cost-efficient scheduling heuristics for deadline constrained workloads on hybrid clouds," in *Third IEEE International Conference on Coud Computing Technology and Science (CloudCom), Athens, Greece*, 2011, pp. 320–327.

[41] V. C. Emeakaroha, I. Brandic, M. Maurer, and I. Breskovic, "Sla-aware application deployment and resource allocation in clouds," in *35th IEEE Annual Computer Software and Applications Conference Workshops (COMPSACW),*, 2011, pp. 298–303.

[42] K. Alhamazani, R. Ranjan, F. Rabhi, L. Wang, and K. Mitra, "Cloud monitoring for optimizing the QoS of hosted applications," in *4th IEEE International Conference on Cloud Computing Technology and Science, Taipei, Taiwan*, 2012, pp. 765–770.

[43] I. Foster, Y. Zhao, I. Raicu, and S. Lu, "Cloud computing and grid computing 360-degree compared," in *Grid Computing Environments Workshop,Austin, TX*, 2008, pp. 1–10.

[44] R. Kaur, "A review of computing technologies: Distributed, utility, cluster, grid and cloud computing," *International Journal of Advanced Research in Computer Science and Software Engineering*, vol. 5, no. 2, pp. 144–148, 2015.

[45] R. Buyya, R. N. Calheiros, and X. Li, "Autonomic cloud computing: Open challenges and architectural elements," in *3rd International Conference on Emerging Applications of Information Technology, Kolkata, India*, 2012, pp. 3–10.

[46] S. Kermally, *Management Ideas in Brief*. Oxford, UK: Butterworth-Heinemann, 1997.

[47] M. Boniface, B. Nasser, J. Papay, S. C. Phillips, A. Servin, X. Yang, Z. Zlatev, S. V. Gogouvitis, G. Katsaros, K. Konstanteli, G. Kousiouris, A. Menychtas, and D. Kyriazis, "Platform-as-a-Service architecture for real-time quality of service management in clouds," in *Fifth International Conference on Internet and Web Applications and Services, Barcelona, Spain*, 2010, pp. 155–160.

[48] P. D. Manuel, S. T. Selvi, and M. I. Abd-El Barr, "A novel trust management system for cloud computing - IaaS providers," *Journal of Combinatorial Mathematics and Combinatorial Computing*, vol. 79, pp. 3–22, 2011.

Universiti Utara Malaysia

[49] P. Manuel, "A trust model of cloud computing based on quality of service," *Annals of Operations Research*, pp. 1–12, 2013.

[50] L. Gu, J. Zhong, C. Wang, Z. Ni, and Y. Zhang, "Trust model in cloud computing environment based on fuzzy theory," *International Journal of Computers Communications and Control*, vol. 9, no. 5, pp. 570–583, 2014.

[51] Y. Wang, J. Zhang, and J. Vassileva, "Super agent based framework for reputation management and community formation in decentralized systems," *Computational Intelligence*, pp. 1–26, 2014.

[52] R. Prodan and S. Ostermann, "A survey and taxonomy of Infrastructure as a Service and web hosting cloud providers," in *10th IEEE/ACM International Conference on Grid Computing, Banff, Alberta, Canada*, 2009, pp. 17–25.

[53] N. R. G. Charan, S. T. Rao, and P. V. S. Srinivas, "Deploying an application on the cloud," *International Journal of Advanced Computer Science and Applications*, vol. 2, no. 5, pp. 119–125, 2011.

[54] J. Peng, X. Zhang, Z. Lei, B. Zhang, W. Zhang, and Q. Li, "Comparison of several cloud computing platforms," in *Second International Symposium on Information Science and Engineering, Beijing, China*, 2009, pp. 23–27.

[55] M. Zhou, R. Zhang, D. Zeng, and W. Qian, "Services in the cloud computing era: A survey," in *Fourth International Universal Communication Symposium, Beijing, China*, 2010, pp. 40–46.

[56] J. Dykstra and A. T. Sherman, "Acquiring forensic evidence from Infrastructure-as-a-Service cloud computing: Exploring and evaluating tools, trust, and techniques," *Digital Investigation*, vol. 9, pp. S90–S98, 2012.

[57] K. Hashizume, E. B. Fernandez, and M. M. Larrondo-Petrie, "Cloud service model patterns," in *19th Conference Pattern Languages of Programs, Tucson, AZ, USA*, 2012.

[58] G. Kulkarni, P. Khatawkar, and J. Gambhir, "Cloud computing-platform as service," *International Journal of Engineering and Advanced Technology*, vol. 1, no. 2, pp. 115–120, 2011.

[59] J. Kong, "Protecting the confidentiality of virtual machines against untrusted host," in *International Symposium on Intelligence Information Processing and Trusted Computing (IPTC), Huanggang, China*, 2010, pp. 364–368.

[60] M. A. Bamiah and S. N. Brohi, "Exploring the cloud deployment and service delivery models," *International Journal of Research and Reviews in Information Sciences*, vol. 1, no. 3, pp. 77–80, 2011.

[61] L. Savu, "Cloud computing: Deployment models, delivery models, risks and research challenges," in *International Conference on Computer and Management, Wuhan, China*, 2011, pp. 1–4.

[62] L. Wang, J. Zhan, W. Shi, and Y. Liang, "In cloud, can scientific communities benefit from the economies of scale?" *IEEE Transactions on Parallel And Distributed Systems*, vol. 23, no. 2, pp. 296–303, 2012.

[63] D. Velev and P. Zlateva, *Open Research Problems in Network Security*, ser. Lecture Notes in Computer Science. Berlin Heidelberg: Springer, 2011, vol. 6555, ch. Cloud Infrastructure Security, pp. 140–148.

[64] J. M. Pedersen, M. T. Riaz, J. C. Junior, B. Dubalski, D. Ledzinski, and A. Patel, "Assessing measurements of QoS for global cloud computing services," in *9th IEEE International Conference on Dependable, Autonomic and Secure Computing, Sydney, Australia*, 2011, pp. 682–689.

[65] X. Liu, Y. Yang, D. Yuan, G. Zhang, W. Li, and D. Cao, "A generic QoS framework for cloud workflow systems," in *9th IEEE International Conference on Dependable, Autonomic and Secure Computing, Sydney, Australia*, 2011, pp. 713–720.

[66] W. Li, Q. Zhang, J. Wu, J. Li, and H. Zhao, "Trust-based and QoS demand clustering analysis customizable cloud workflow scheduling strategies," in *IEEE International Conference on Cluster Computing Workshops, Beijing, China*, 2012, pp. 111–119.

[67] M. S. Mushtaq, B. Augustin, and A. Mellouk, "Empirical study based on machine learning approach to assess the QoS/QoE correlation," in *17th European Conference on Networks and Optical Communications, Vilanova i la Geltru, Spain*, 2012, pp. 1–7.

[68] J. Ma, R. Sun, and A. Abraham, "Toward a lightweight framework for monitoring public clouds," in *Fourth International Conference on Computational Aspects of Social Networks, Sao Carlos, Brazil*, 2012, pp. 361–365.

[69] Q. Zhu and G. Agrawal, "Resource provisioning with budget constraints for adaptive applications in cloud environments," *IEEE Transactions on Services Computing*, vol. 5, no. 4, pp. 497–511, 2012.

[70] J. Li, Q. Wang, D. Jayasinghe, S. Malkowski, P. Xiong, C. Pu, Y. Kanemasa, and M. Kawaba, "Profit-based experimental analysis of iaas cloud performance: Impact of software resource allocation," in *Ninth IEEE International Conference on Services Computing, Honolulu, HI, USA*, 2012, pp. 344–351.

[71] B. Sharma, R. K. Thulasiram, P. Thulasiraman, S. K. Garg, and R. Buyya, "Pricing cloud compute commodities: A novel financial economic model," in *12th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing, Ottawa, ON, Canada*, 2012, pp. 451–457.

[72] D. Adami, C. Callegari, S. Giordano, and M. Pagano, "A hybrid multidimensional algorithm for network-aware resource scheduling in clouds and grids," in *IEEE International Conference on Communications, Ottawa, ON, Canada*, 2012, pp. 1297–1301.

Universiti Utara Malaysia

[73] S. C. Phillips, V. Engen, and J. Papay, "Snow white clouds and the seven dwarfs," in *Third IEEE International Conference on Cloud Computing Technology and Science, Athens, Greece*, 2011, pp. 738–745.

[74] A. Gohad, K. Ponnalagu, and N. C. Narendra, "Model driven provisioning in multi-tenant clouds," in *Annual Service Research and Innovation Institute Global Conference*, 2012, pp. 11–20.

[75] G. N. Iyer and B. Veeravalli, "On the resource allocation and pricing strategies in compute clouds using bargaining approaches," in *17th IEEE International Conference on Networks, Singapore*, 2011, pp. 147–152.

[76] S. P. Sanchez, G. Casale, B. Scotney, S. McClean, G. Parr, and S. Dawson, "Markovian workload characterization for QoS prediction in the cloud," in *IEEE International Conference on Cloud Computing, Washington, DC, USA*, 2011, pp. 147–154.

[77] Y. Kouki, T. Ledoux, and R. Sharrock, "Cross-layer SLA selection for cloud services," in *First International Symposium on Network Cloud Computing and Applications, Toulouse, France*, 2011, pp. 143–147.

[78] L. Wu, S. K. Garg, and R. Buyya, "SLA-based resource allocation for Software as a Service provider (SaaS) in cloud computing environments," in *11th IEEE/ACM International Symposium on Cluster, Cloud and Grid Computing, Newport Beach, CA, USA*, 2011, pp. 195–204.

[79] T. Chauhan, S. Chaudhary, V. Kumar, and M. Bhise, "Service level agreement parameter matching in cloud computing," in *World Congress on Information and Communication Technologies, Mumbai, India*, 2011, pp. 564–570.

[80] R. S. Padilla, S. K. Milton, and L. W. Johnson, "Components of service value in business-tobusiness cloud computing," *Journal of Cloud Computing: Advances, Systems and Applications*, vol. 4, no. 15, pp. 1–20, 2015.

[81] S. V. Gogouvitis, V. Alexandrou, N. Mavrogeorgi, S. Koutsoutos, D. Kyriazis, and T. Varvarigou, "A monitoring mechanism for storage clouds," in *Second International Conference on Cloud and Green Computing, Xiangtan, Hunan, China*, 2012, pp. 153–159.

[82] F. Stoicuta, I. Ivanciu, E. Minzat, A. B. Rus, and V. Dobrota, "An opennetinf-based cloud computing solution for cross-layer qos: Monitoring part using ios terminals," in *10th International Symposium on Electronics and Telecommunications, Timisoara, Romania*, 2012, pp. 167–170.

[83] K. Saravanan and M. L. Kantham, "An enhanced QoS architecture based framework for ranking of cloud services," *International Journal of Engineering Trends and Technology*, vol. 4, no. 4, pp. 1022–1031, 2013.

[84] N. Kumar and S. Agarwal, "QoS based cloud service provider selection framework," *Research Journal of Recent Sciences*, vol. 3, pp. 7–12, 2014.

Universiti Utara Malaysia

[85] M. K. Goyal, A. Aggarwal, P. Gupta, and P. Kumar, "QoS based trust management model for cloud IaaS," in *2nd IEEE International Conference on Parallel, Distributed and Grid Computing, Solan, India*, 2012, pp. 843–847.

[86] R. F. AlCattan, "Integration of cloud computing and web 2.0 collaboration technologies in e-learning," *International Journal of Computer Trends and Technology*, vol. 12, no. 1, pp. 46–55, 2014.

[87] N. Phaphoom, X. Wang, and P. Abrahamsson, "Foundations and technological landscape of cloud computing," *ISRN Software Engineering*, vol. 2013, pp. 1–31, 2013.

[88] R. Kaur, "Cloud computing," *International Journal of Computer Science and Technology*, vol. 2, no. 3, pp. 373–381, 2011.

[89] A. Abdelmaboud, D. N. A. Jawawi, I. Ghani, A. Elsafi, and B. Kitchenham, "Quality of service approaches in cloud computing," *Journal of Systems and Software*, vol. 101, no. C, pp. 159–179, 2015.

[90] G. V. Bochmann, B. Kerherve, H. Lutfiyya, M. V. M. Salem, and H. Ye, "Introducing QoS to electronic commerce applications," in *2nd International Symposium on Electronic Commerce (ISEC), Hong Kong*, 2001, pp. 138–147.

[91] S. K. Garg, S. K. Gopalaiyengar, and R. Buyya, "SLA-based resource provisioning for heterogeneous workloads in a virtualized cloud datacenter," in *11th International Conference on Algorithms and Architectures for Parallel Processing (ICA3PP 2011), Melbourne, Australia*, ser. LNCS 7016, vol. I. Springer, 2011, pp. 371–384.

[92] D. Carrera, M. Steinder, I. Whalley, J. Torres, and E. Ayguade, "Enabling resource sharing between transactional and batch workloads using dynamic application placement," in *9th ACM/IFIP/USENIX International Conference on Middleware. Leuven, Belgium*, 2008, pp. 203–222.

[93] N. Thio and S. Karunasekera, "Automatic measurement of a QoS metric for web service recommendation," in *Australian Software Engineering Conference, Brisbane, Australia*, 2005, pp. 202 –211.

[94] G. E. Goncalves, P. T. Endo, T. D. Cordeiro, A. V. de Almeida Palhares, D. Sadok, J. Kelner, B. Melander, and J. E. Mangs, "Resource allocation in clouds: Concepts, tools and research challenges," in *29th Brazilian Symposium on Computer Networks and Distributed Systems, Campo Grande, MS, Brazil*, 2011, pp. 197–240.

[95] S. Mulay and S. Jain, "Enhanced equally distributed load balancing algorithm for cloud computing," *International Journal of Research in Engineering and Technology*, vol. 2, no. 6, pp. 976–980, 2013.

[96] S. Begum and C. S. R. Prashanth, "Review of load balancing in cloud computing," *International Journal of Computer Science Issues*, vol. 10, no. 1, pp. 343–352, 2013.

Universiti Utara Malaysia

[97] T. K. Chiew and K. Renaud, "Disassembling web site response time," in *12th European Conference on Information Technology Evaluation, Turku, Finland*, 2005, pp. 137–145.

[98] G. Wang and T. S. E. Ng, "The impact of virtualization on network performance of Amazon EC2 data center," in *IEEE INFOCOM, San Diego, CA*, 2010, pp. 1–9.

[99] M. Alhamad, T. Dillon, C. Wu, and E. Chang, "Response time for cloud computing providers," in *12th International Conference on Information Integration and Web-based Applications & Services, Paris, France*, 2010, pp. 603–606.

[100] D. Ardagna, G. Casale, M. Ciavotta, J. F. Perez, and W. Wang, "Quality-of-service in cloud computing: Modeling techniques and their applications," *Journal of Internet Services and Applications*, vol. 5, no. 11, pp. 1–17, 2014.

[101] P. Cremonesi, K. Dhyani, and A. Sansottera, "Service time estimation with a refinement enhanced hybrid clustering algorithm," in *17th International Conference on Analytical and Stochastic Modeling Techniques and Applications, Cardiff, UK*, 2010, pp. 291–305.

[102] A. I. El-Nashar, "To parallelize or not to parallelize, speed up issue," *International Journal of Distributed and Parallel Systems*, vol. 2, no. 2, pp. 14–28, 2011.

[103] C. Wang, L. Xing, H. Wang, Z. Zhang, and Y. Dai, "Processing time analysis of cloud services with retrying fault-tolerance technique," in *First IEEE International Conference on Communications in China, Beijing, China*, 2012, pp. 63–67.

[104] F. S. Ahmed, A. Aslam, S. Ahmed, and M. A. Q. Bilal, "Comparative study of scalability and availability in cloud and utility computing," *Journal of Emerging Trends in Computing and Information Sciences*, vol. 2, no. 12, pp. 705–713, 2011.

[105] L. Zhao and K. Sakurai, "Improving cost-efficiency through failure-aware server management and scheduling in cloud," in *2nd International Conference on Cloud Computing and Services Science, Porto, Portugal*, 2013, pp. 23–38.

[106] M. G. Avram, "Advantages and challenges of adopting cloud computing from an enterprise perspective," in *7th International Conference Interdisciplinarity in Engineering, Mures, Romania*, 2013, pp. 529–534.

[107] Y. S. Dai, B. Yang, J. Dongarra, and G. Zhang, "Cloud service reliability: Modeling and analysis," in *15th IEEE Pacific Rim International Symposium on Dependable Computing, Shanghai, China*, 2009, pp. 1–17.

[108] N. Yadav, V. B. Singh, and M. Kumari, "Generalized reliability model for cloud computing," *International Journal of Computer Applications*, vol. 88, no. 14, pp. 13–16, 2014.

Universiti Utara Malaysia

[109] T. Lynn, P. Healy, R. McClatchey, J. Morrison, C. Pahl, and B. Lee, "The case for cloud service trustmarks and Assurance-as-a-Service," in *3rd International Conference on Cloud Computing and Services Science, Aachen, Germany*, 2013, pp. 1–6.

[110] R. Scandariato, Y. Ofek, P. Falcarin, and M. Baldi, "Application-oriented trust in distributed computing," in *Third International Conference on Availability, Reliability and Security, Barcelona, Spain*, 2008, pp. 434–439.

[111] N. A. Al-Saiyd and N. Sail, "Data integrity in cloud computing security," *Journal of Theoretical and Applied Information Technology*, vol. 58, no. 3, pp. 570–581, 2013.

[112] H. Yu, Z. Shen, C. Miao, C. Leung, and D. Niyato, "A survey of trust and reputation management systems in wireless communications," *Proceedings of the IEEE*, vol. 98, no. 10, pp. 1755–1772, 2010.

[113] Z. Gan, J. He, and Q. Ding, "Trust relationship modelling in e-commerce-based social network," in *International conference on computational intelligence and security, Beijing, China*, 2009, pp. 206–210.

[114] D. H. McKnight and N. L. Chervany, "Conceptualizing trust: A typology and e-commerce customer relationships model," in *34th Hawaii International Conference on System Sciences, Island of Maui, HI, USA*, 2001.

[115] W. Wang and G. S. Zeng, "Bayesian cognitive trust model based self-clustering algorithm for MANETs," *Science China Information Sciences*, vol. 53, no. 3, pp. 494–505, 2010.

[116] M. Gomez, J. Carbo, and E. C. Benac, "A cognitive trust and reputation model for the ART testbed," *Inteligencia Artificial. Revista Iberoamericana de Inteligencia Artificial (in English)*, vol. 12, no. 39, pp. 29–40, 2008.

[117] H. Quan and J. Wu, "CATM: A cognitive-inspired agent-centric trust model for online social networks," in *Ninth Annual IEEE International Conference on Pervasive Computing and Communications, Seattle, WA, USA*, 2011.

[118] C. Castelfranchi, R. Falcone, and G. Pezzulo, "Trust in information sources as a source for trust: A fuzzy approach," in *Second International Joint Conference on Autonomous Agents and Multiagent Systems, Melbourne, Australia*, 2003, pp. 89–96.

[119] S. de Paoli, G. R. Gangadharan, A. Kerr, V. D. Andrea, M. Serrano, and D. Botvich, "Toward trust as result: An interdisciplinary approach," *Sprouts: Working Papers on Information Systems*, vol. 10, no. 8, pp. 1–6, 2010.

[120] M. Akhoondi, J. Habibi, and M. Sayyadi, "Towards a model for inferring trust in heterogeneous social networks," in *Second Asia International Conference on Modelling & Simulation, Kuala Lumpur, Malaysia*, 2008, pp. 52–58.

[121] R. A. Menkes, "An economic analysis of trust, social capital and the legislation of trust," Master's thesis, University of Ghent, Belgium, 2007.

Universiti Utara Malaysia

[122] J. Zhang and R. Cohen, "Design of a mechanism for promoting honesty in e-marketplaces," in *22nd Conference on Artificial Intelligence, AI and the Web Track, Vancouver, BC, Canada*, 2007.

[123] J. Zhang, "Promoting honesty in electronic marketplaces: Combining trust modeling and incentive mechanism design," Ph.D. dissertation, University of Waterloo, Canada, 2009.

[124] S. Mittal and K. Deb, "Optimal strategies of the iterated prisoner's dilemma problem for multiple conflicting objectives," in *IEEE Symposium on Computational Intelligence and Games, Reno, NV, USA*, 2006, pp. 197–204.

[125] J. Zhou, J. Wang, R. Liang, and Y. Zhang, "Flexible service analysis based on the prisoner's dilemma of service," in *6th International Conference on Service Systems and Service Management, Xiamen, china*, 2009, pp. 434–437.

[126] H. Huang, G. Zhu, and S. Jin, "Revisiting trust and reputation in multi-agent systems," in *ISECS International Colloquium on Computing, Communication, Control and Management, Guangzhou, China*, 2008, pp. 424–429.

[127] L. Mui, "Computational models of trust and reputation: Agents, evolutionary games and social networks," Ph.D. dissertation, Massachusetts Institute of Technology, Boston, MA, USA, 2002.

[128] M. Momani and S. Challa, "Survey of trust models in different network domains," *International Journal of Ad hoc, Sensor & Ubiquitous Computing*, vol. 1, no. 3, pp. 1–19, 2010.

[129] T. Y. Chuang, "Trust with social network learning in e-commerce," in *IEEE International Conference on Communications Workshops (ICC), Capetown, South Africa*, 2010, pp. 1–6.

[130] M. Adamski, A. Arenas, A. Bilas, P. Fragopoulou, V. Georgiev, A. Hevia, G. Jankowski, B. Matthews, N. Meyer, J. Platte, and M. Wilson, "Trust and security in grids: A state of the art," CoreGRID, European Union, Tech. Rep. WHP-0001, 2008.

[131] A. Gouglidis and I. Mavridis, "A foundation for defining security requirements in grid computing," in *13th Panhellenic Conference on Informatics, Corfu, Greece*, 2009, pp. 180–184.

[132] L. B. de Oliveira and C. A. Maziero, "A trust model for a group of e-mail servers," *CLEI Electronic Journal*, vol. 11, no. 2, pp. 1–11, 2008.

[133] Q. Zhang, T. Yu, and K. Irwin, "A classification scheme for trust functions in reputation-based trust management," in *International Workshop on Trust, Security, and Reputation on the Semantic Web, Hiroshima, Japan*, 2004.

[134] Z. Shen, L. Li, F. Yan, and X. Wu, "Cloud computing system based on trusted computing platform," in *International Conference on Intelligent Computation Technology and Automation (ICICTA), Changsha, China*, vol. 1, 2010, pp. 942–945.

[135] Z. Shen and Q. Tong, "The security of cloud computing system enabled by trusted computing technology," in *2nd International Conference on Signal Processing Systems (ICSPS), Dalian, China*, vol. 2, 2010, pp. 11–15.

[136] K. M. Khan and Q. Malluhi, "Establishing trust in cloud computing," *IEEE IT Professional*, vol. 12, no. 5, pp. 20–27, 2010.

[137] H. Takabi, J. B. D. Joshi, and G. J. Ahn, "Securecloud: Towards a comprehensive security framework for cloud computing environments," in *34th Annual IEEE Computer Software and Applications Conference Workshops, Seoul, South Korea*, 2010, pp. 393–398.

[138] Z. Song, J. Molina, and C. Strong, "Trusted anonymous execution: A model to raise trust in cloud," in *9th International Conference on Grid and Cooperative Computing (GCC), Nanjing, China*, 2010, pp. 133–138.

[139] H. Sato, A. Kanai, and S. Tanimoto, "A cloud trust model in a security aware cloud," in *10th IEEE/IPSJ International Symposium on Applications and the Internet, Seoul, South Korea*, 2010, pp. 121–124.

[140] W. Li, L. Ping, and X. Pan, "Use trust management module to achieve effective security mechanisms in cloud environment," in *International Conference on Electronics and Information Engineering, Kyoto, Japan*, 2010, pp. 14–19.

[141] T. F. Wang, B. S. Ye, Y. W. Li, and Y. Yang, "Family gene based cloud trust model," in *International Conference on Educational and Network Technology, Qinhuangdao, China*, 2010, pp. 540–544.

[142] T. F. Wang, B. S. Ye, Y. W. Li, and L. S. Zhu, "Study on enhancing performance of cloud trust model with family gene technology," in *3rd IEEE International Conference on Computer Science and Information Technology, Chengdu, China*, 2010, pp. 122–126.

[143] T. S. Somasundaram, B. R. Amarnath, R. Kumar, P. Balakrishnan, K. Rajendar, R. Rajiv, K. Govindarajan, G. R. Britto, E. Mahendran, and B. Madusudhanan, "CARE resource broker: A framework for scheduling and supporting virtual resource management," *Future Generation Computer Systems*, vol. 26, no. 3, pp. 337–347, 2010.

[144] P. D. Manuel, T. Selve, and M. I. Abd-EI Barr, "Trust management system for grid and cloud resources," in *First International Conference on Advanced Computing (ICAC 2009), Chennai, India*, 2009, pp. 176–181.

[145] M. Alhamad, T. Dillon, and E. Chang, "SLA-based trust model for cloud computing," in *13th International Conference on Network-Based Information Systems, Takayama, Japan*, 2010, pp. 321–324.

[146] X. Y. Li, L. T. Zhou, Y. Shi, and Y. Guo, "A trusted computing environment model in cloud architecture," in *Ninth International Conference on Machine Learning and Cybernetics, Qingdao, China*, 2010, pp. 2843–2848.

[147] Z. Yang, L. Qiao, C. Liu, C. Yang, and G. Wan, "A collaborative trust model of firewall-through based on cloud computing," in *14th International Conference on Computer Supported Cooperative Work in Design, Shanghai, China*, 2010, pp. 329–334.

[148] J. Fu, C. Wang, Z. Yu, J. Wang, and J. G. Sun, "A watermark-aware trusted running environment for software clouds," in *Fifth Annual ChinaGrid Conference, Guangzhou, China*, 2010, pp. 144–151.

[149] R. Ranchal, B. Bhargava, L. B. Othmane, L. Lilien, A. Kim, M. Kang, and M. Linderman, "Protection of identity information in cloud computing without trusted third party," in *29th IEEE International Symposium on Reliable Distributed Systems, New Delhi, India*, 2010, pp. 1060–9857.

[150] L. T. M. Blessing and A. Chakrabarti, *DRM, A Design Research Methodology*. London, UK: Springer, 2009.

[151] H. Birkhofer, "Are we aware of what we are doing in design research?" in *3rd International Conference on Design Engineering and Science, Pilsen, Czech Republic*, 2014, pp. 1–10.

[152] A. Wikstrom, "A design process based on visualization," Licentiate Thesis, Malardalen University, Sweden, 2010.

[153] M. Firdhous, O. Ghazali, and S. Hassan, "Trust management in cloud computing - A critical review," *International Journal on Advances in ICT for Emerging Regions (ICTer)*, vol. 4, no. 2, pp. 24–36, 2011.

[154] ——, "Trust and trust management in cloud computing - a survey," InterNetworks Research Lab, School of Computing, Universiti Utara Malaysia, Sintok, Kedah, Malaysia, Tech. Rep. UUM/CAS/InterNetWorks/TR2011-01, 2011.

[155] M. Firdhous, S. Hassan, and O. Ghazali, "A comprehensive survey on quality of service implementations in cloud computing," *International Journal of Scientific & Engineering Research*, vol. 4, no. 5, pp. 118–123, 2013.

[156] M. Firdhous, S. Hassan, O. Ghazali, and M. Mahmuddin, *Cloud Systems in Supply Chains*. Hampshire, UK: Palgrave Macmillan, 2015, ch. Evaluating Cloud System Providers: Models, Methods and Applications, pp. 121–149.

[157] N. A. Sultan, "Reaching for the cloud: How SMEs can manage," *International Journal of Information Management*, vol. 31, no. 3, pp. 272–278, 2011.

[158] G. Feng, "Applications of Matlab in mathematical analysis," *Journal of Software*, vol. 6, no. 7, pp. 1225–1229, 2011.

[159] R. Farrugia, "Modular programming - some lessons learned and benefits gained," in *Computational Science Symposium, Brighton, England*, 2011, pp. 1–6.

[160] W. J. Palm, *Introduction to Matlab 7 for Engineers*. New York: McGraw Hill, 2004.

[161] O. Balci, "Verification, validation and accreditation of simulation models," in *29th conference on Winter simulation, Atlanta, GA*, 1997, pp. 135–141.

[162] T. L. Paez, "Introduction to model validation," in *Conference & Exposition on Structural Dynamics - Model Verification & Validation, Orlando, FL*, 2009, pp. 1–11.

[163] K. Iwanicki, P. Horban, P. Glazar, and K. Strzelecki, "Bringing modern unit testing techniques to sensornets," *ACM Transactions on Sensor Networks*, vol. 11, no. 2, pp. 1–37, 2015.

[164] L. Mariani, M. Pezze, and D. Willmor, *Applying Formal Methods: Testing, Performance, and M/E-Commerce*. Berlin Heidelberg: Springer, 2004, ch. Generation of Integration Tests for Self-Testing Components, pp. 337–350.

[165] R. N. Calheiros, R. Ranjan, A. Beloglazov, C. A. F. de Rose, and R. Buyya, "Cloudsim: A toolkit for modeling and simulation of cloud computing environments and evaluation of resource provisioning algorithms," *Software: Practice and Experience*, vol. 41, no. 1, pp. 23–50, 2011.

[166] R. Buyya, R. Ranjan, and R. N. Calheiros, "Modeling and simulation of scalable cloud computing environments and the cloudsim toolkit: challenges and opportunities," in *7th High Performance Computing and Simulation Conference,Leipzig, Germany*, 2009, pp. 1–11.

[167] R. Malhotra and P. Jain, "Study and comparison of various cloud simulators available in the cloud computing," *International Journal of Advanced Research in Computer Science and Software Engineering*, vol. 3, no. 9, pp. 347–350, 2013.

Universiti Utara Malaysia

[168] W. Zhao, Y. Peng, F. Xie, and Z. Dai, "Modeling and simulation of cloud computing: A review," in *IEEE Asia Pacific Cloud Computing Congress, Shenzhen, China*, 2012, pp. 20–24.

[169] F. Fittkau, S. Frey, and W. Hasselbring, "CDOSim: Simulating cloud deployment options for software migration support," in *IEEE 6th International Workshop on the Maintenance and Evolution of Service-Oriented and Cloud-Based Systems, Trento, Italy*, 2012, pp. 37–46.

[170] Y. Jararweh, Z. Alshara, M. Jarrah, M. Kharbutli, and M. N. Alsaleh, "Teachcloud: A cloud computing educational toolkit," *International Journal of Cloud Computing*, vol. 2, no. 2/3, pp. 1–16, 2013.

[171] G. G. Castane, A. Nunez, and J. Carretero, "iCanCloud: A brief architecture overview," in *10th IEEE International Symposium on Parallel and Distributed Processing with Applications, Madrid, Spain*, 2012, pp. 853–854.

[172] I. Sriram, "SPECI, a simulation tool exploring cloud-scale data centres," in *First International Conference on Cloud Computing, Beijing, China*, 2009, pp. 381–392.

[173] S. Ostermann, K. Plankensteiner, R. Prodan, and T. Fahringer, "GroudSim: An event-based simulation framework for computational grids and clouds," in *Euro-Par 2010 Parallel Processing Workshops, Ischia, Italy*, 2010, pp. 305–313.

[174] G. Keller, M. Tighe, H. Lutfiyya, and M. Bauer, "DCSim: A data centre simulation tool," in *IFIP/IEEE International Symposium on Integrated Network Management, Ghent, Belgium*, 2013, pp. 1090–1091.

[175] B. Wickremasinghe, R. N. Calheiros, and R. Buyya, "Cloudanalyst: A cloudsim-based visual modeller for analysing cloud computing environments and applications," in *24th International Conference on Advanced Information Networking and Applications, Perth, Australia*, 2010, pp. 446–452.

[176] S. K. Garg and R. Buyya, "Networkcloudsim: Modelling parallel applications in cloud simulations," in *4th IEEE/ACM International Conference on Utility and Cloud Computing, Melbourne, Australia*, 2011, pp. 105–113.

[177] R. Malhotra and P. Jain, "Study and comparison of CloudSim simulators in the cloud computing," *SIJ Transactions on Computer Science Engineering & its Applications*, vol. 1, no. 4, pp. 111–115, 2013.

[178] A. Beloglazov and R. Buyya, "Optimal online deterministic algorithms and adaptive heuristics for energy and performance efficient dynamic consolidation of virtual machines in cloud data centers," *Concurrency and Computation: Practice & Experience*, vol. 24, no. 13, pp. 1397–1420, 2012.

[179] C. J. Roy, "Review of code and solution verification procedures for computational simulation," *Journal of Computational Physics*, vol. 205, no. 1, pp. 131–156, 2005.

[180] J. Papcun, "Integrating static code analysis and defect tracking," Master's thesis, Faculty of Informatics, Masaryk University, Brno, Czech Republic, 2014.

[181] T. Arnold, D. Hopton, A. Leonard, and M. Frost, *Professional Software Testing with Visual Studio 2005 Team System: Tools for Software Developers and Test Engineers*. Hoboken, NJ: Wiley, 2007.

[182] J. M. Kelif, "Analytical performance model for Poisson wireless networks with pathloss and shadowing propagation," in *Globecom Workshops, Austin, TX*, 2014, pp. 1528–1532.

[183] I. A. Lawal, A. M. Said, and A. A. Muazu, "Simulation model to improve QoS performance over fixed WiMAX using OPNET," *Research Journal of Applied Sciences, Engineering and Technology*, vol. 6, no. 21, pp. 3933–3945, 2013.

[184] M. Ivanovich, P. Fitzpatrick, J. Li, M. Beresford, and A. Saliba, "Measuring quality of service in an experimental wireless data network," *Australian Telecommunications, Networks and Applications Conference, Perth, WA, Australia*, 2003.

Universiti Utara Malaysia

[185] M. S. Obaidat and N. A. Boudriga, *Fundamentals of Performance Evaluation of Computer and Telecommunications Systems*. Hoboken, NJ: Wiley, 2010.

[186] K. Velten, *Mathematical Modeling and Simulation: Introduction for Scientists and Engineers*. Hoboken, NJ: Wiley, 2008.

[187] A. Doosti and A. M. Ashtiani, "Mathematical modeling: a new approach for mathematics teaching in different levels," in *2nd Meeting of the network of teachers, researchers and undergraduate students of physics and mathematics, Sao Carlos, Brazil*, 2010, pp. 1–9.

[188] K. Soetaert, T. Petzoldt, and R. W. Setzer, "Solving differential equations in R," *The R Journal*, vol. 2, no. 2, pp. 5–15, 2010.

[189] J. A. Cabrera and J. P. T. Higgins, "Graphical displays for meta-analysis: An overview with suggestions for practice," *Resaerch Synthesis Methods*, vol. 1, pp. 66–80, 2010.

[190] R. K. Jain, *The Art of Computer Systems Performance Analysis: Techniques for Experimental Design, Measurement, Simulation, and Modeling*. Wiley, 1991.

[191] R. Sherwood, G. Gibb, K. K. Yap, G. Appenzeller, M. Casado, N. McKeown, and G. Parulkar, "Can the production network be the testbed?" in *9th USENIX conference on Operating systems design and implementation, Vancouver, BC, Canada*, 2010, pp. 1–14.

[192] S. B. Lee, E. Bajaj, L. Breslau, D. Estrin, K. Fall, S. Floyd, P. Haldar, H. Mark, A. Helmy, J. Heidemann, P. Huang, S. Kumar, S. Mccanne, and H. Yu, "Improving simulation for network research," Department of Computer Science, University of Southern California, Los Angeles, CA, Technical Report 99-702, 1999.

[193] E. Weingartner, H. vom Lehn, and K. Wehrle, "A performance comparison of recent network simulators," in *IEEE International Conference on Communications, Dresden, Germany*, 2009, pp. 1–5.

[194] M. N. Ismail and A. M. Zin, "Comparing the accuracy of network utilization performance between real network and simulation model for Local Area Network (LAN)," *I. J. Communications, Network and System Sciences*, vol. 4, pp. 339–349, 2008.

[195] R. Shaikh and M. Sasikumar, "Cloud simulation tools: A comparative analysis," *International Journal of Computer Applications*, pp. 11–14, 2013.

[196] T. Goyal, A. Singh, and A. Agrawal, "Cloudsim: Simulator for cloud computing infrastructure and modeling," *Procedia Engineering*, vol. 38, pp. 3566–3572, 2008.

[197] R. N. Calheiros, R. Ranjan, C. A. F. De Rose, and R. Buyya, "Cloudsim: A novel framework for modeling and simulation of cloud computing infrastructures and services," Grid Computing and Distributed Systems Laboratory, The University of Melbourne, Australia, Technical Report GRIDS-TR-2009-1, 2009.

Universiti Utara Malaysia

[198] A. Nunez, J. L. V. Poletti, A. C. Caminero, G. G. Castane, J. Carretero, and I. M. Llorente, "icancloud: A flexible and scalable cloud infrastructure simulator," *Journal of Grid Computing*, vol. 10, no. 1, pp. 185–209, 2012.

[199] A. Nunez, J. Fernandez, J. D. Garcia, L. Prada, and J. Carretero, "Simcan: A simulator framework for computer architectures and storage networks," in *1st international conference on Simulation Tools and Techniques for Communications, Networks and Systems, Marseille, France*, 2008, pp. 1–8.

[200] B. Pranggono, D. Alboaneen, and H. Tianfield, *Simulation Technologies in Networking and Communications: Selecting the Best Tool for the Test*. Boca Raton, FL: CRC Press, 2014, ch. Simulation Tools for Cloud Computing, pp. 311–336.

[201] S. K. Garg, C. S. Yeo, and R. Buyya, "Green cloud framework for improving carbon efficiency of clouds," in *17th International European Conference on Parallel and Distributed Computing, Bordeaux, France*, 2011, pp. 491–502.

[202] R. Kaur and N. S. Ghumman, "A survey and comparison of various cloud simulators available for cloud environment," *International Journal of Advanced Research in Computer and Communication Engineering*, vol. 4, no. 5, pp. 605–608, 2015.

[203] U. Sinha and M. Shekhar, "Comparison of various cloud simulation tools available in cloud computing," *International Journal of Advanced Research in Computer and Communication Engineering*, vol. 4, no. 3, pp. 171–176, 2015.

[204] C. G. Garino, C. Mateos, and E. Pacini, *Cloud Computing and Big Data*. Amsterdam: IOS Press, 2013, ch. ACO-based Dynamic Job Scheduling of Parametric Computational Mechanics Studies on Cloud Computing Infrastructures, pp. 103–122.

[205] I. Lazar and J. Husar, "Validation of the serviceability of the manufacturing system using simulation," *Journal on Efficiency and Responsibility in Education and Science*, vol. 5, no. 4, pp. 252–261, 2012.

[206] P. K. Suri and P. Ranjan, "Comparative analysis of software effort estimation techniques," *International Journal of Computer Applications*, vol. 48, no. 21, pp. 12–19, 2012.

[207] V. Govindarajalu and V. S. S. Kumar, "Integration of simulation modeling and comparison of scheduling methods to minimize the makespan in a printing industry," *Advanced Materials Research*, vol. 488-489, pp. 1119–1124, 2012.

[208] O. A. C. Mendoza, "A simulator prototype for an ERP system," MSc Thesis, Department of Applied Mathematics and Computer Science, Technical University of Denmark, Denmark, 2005.

[209] M. Hassan and R. Jain, *High Performance TCP/IP Networking: Concepts, Issues and Solutions*. Upper Saddle River, NJ: Prentice Hall, 2004.

Universiti Utara Malaysia

[210] J. Singh, "Study study of response time in cloud computing response time in cloud computing," *I.J. Information Engineering and Electronic Business*, vol. 5, pp. 36–43, 2014.

[211] K. Davies. (2013) Sizes for virtual machines. Microsoft Azure. - Accessed on 05/10/2013. [Online]. Available: https://azure.microsoft.com/en-us/documentation/articles/virtual-machines-size-specs/

[212] S. Frey, C. Luthje, and C. Reich, "Key performance indicators for cloud computing SLAs," in *Fifth International Conference on Emerging Network Intelligence, Porto, Portugal*, 2013, pp. 60–64.

[213] A. Hanemann, A. Liakopoulos, M. Molina, and D. M. Swany, "A study on network performance metrics and their composition," *Campus-Wide Information Systems*, vol. 23, no. 4, pp. 268–282, 2006.

[214] F. Sabahi, "Cloud computing reliability, availability and serviceability (RAS): Issues and challenges," *International Journal on Advances in ICT for Emerging Regions*, vol. 4, no. 2, pp. 12–23, 2011.

[215] J. B. Villegas-Puyod, "Cost effective cloud computing for real-time applications," in *Tenth International Conference on ICT and Knowledge Engineering, Bangkok, Thailand*, 2012, pp. 171–174.

[216] A. O. Afolabi and E. R. Adagunodo, "Analysis of robustness of a developed e-learning system," *International Journal of Advanced Research in Computer Science and Software Engineering*, vol. 3, no. 8, pp. 23–31, 2013.

[217] H. N. Erb, "A statistical approach for calculating the minimum number of animals needed in research," *Institute for Laboratory Animal Research Journal*, vol. 32, no. 1, pp. 11–16, 1990.

[218] J. S. Kim and R. J. Dailey, *Biostatistics for Oral Healthcare*. Oxford, UK: Wiley-Blackwell, 2008, ch. Confidence Intervals and Sample Size, pp. 113–126.

[219] T. Z. Fahidy, "Some applications of bayes' rule in probability theory to electrocatalytic reaction engineering," *International Journal of Electrochemistry*, vol. 2011, pp. 1–5, 2011.

[220] P. Damien, P. Dellaportas, N. G. Polson, and D. A. Stephens, Eds., *Bayesian Theory and Applications*. Oxford, UK: Oxford University Press, 2013.

[221] K. S. Kim and Y. S. Choi, "Bayesian network approach to computerized adaptive testing," *International Journal of Smart Home*, vol. 6, no. 3, pp. 75–82, 2012.

[222] M. Y. Lin, "Bayesian statistics," School of Public Health, Boston University, Boston, MA, Tech. Rep., 2013.

[223] K. Huang, I. King, and M. R. Lyu, "Learning maximum likelihood semi-naive bayesian network classifier," in *IEEE International Conference on Systems, Man and Cybernetics, Yasmine Hammamet, Tunisia*, 2002, pp. 1–6.

[224] A. M. Carvalho, A. L. Oliveira, and M. F. Sagot, "Efficient learning of bayesian network classifiers: An extension to the TAN classifier," in *20th Australian Joint Conference on Artificial Intelligence, Gold Coast, Australia*, 2007, pp. 16–25.

[225] Y. Jing, V. Pavlovic, and J. M. Rehg, "Boosted bayesian network classifiers," *Machine Learning*, vol. 73, no. 2, pp. 155–184, 2008.

[226] W. M. Grudzewski, I. K. Hejduk, A. Sankowska, and M. Wantuchowicz, *Trust Management in Virtual Work Environments: A Human Factors Perspective*. Boca Raton, FL: CRC Press, 2008.

[227] M. Carbone, M. Nielsen, and V. Sassone, "A formal model for trust in dynamic networks," in *1st International Conference on Software Engineering and Formal Methods, Brisbane, Australia*, 2003, pp. 54–61.

[228] B. S. Vanneste, P. Puranam, and T. Kretschmer, "Trust over time in exchange relationships: Meta-analysis and theory," *Strategic Management Journal*, vol. 35, no. 12, pp. 1891–1902, 2014.

[229] A. Shawish and M. Salama, *Inter-cooperative Collective Intelligence: Techniques and Applications, Studies in Computational Intelligence*. Berlin Heidelberg: Springer, 2014, ch. Cloud Computing: Paradigms and Technologies, pp. 39–67.

[230] M. Gabel, A. Schuster, and D. Keren, "Communication-efficient distributed variance monitoring and outlier detection for multivariate time series," in *28th IEEE International Parallel & Distributed Processing Symposium, Phoenix, AZ*, 2014, pp. 37–47.

[231] L. M. Spizman, "Developing statistical based earnings estimates: Median versus mean earnings," *Journal of Legal Economics*, vol. 19, no. 2, pp. 77–82, 2013.

[232] B. Karlik and A. V. Olgac, "Performance analysis of various activation functions in generalized mlp architectures of neural networks," *International Journal of Artificial Intelligence And Expert Systems*, vol. 1, no. 4, pp. 111–122, 2010.

[233] A. Tsoularis and J. Wallace, "Analysis of logistic growth models," *Mathematical Biosciences*, vol. 179, no. 1, pp. 21–55, 2002.

[234] Y. Cai and D. Hames, "Minimum sample size determination for generalized extreme value distribution," *Communications in Statistics - Simulation and Computation*, vol. 40, pp. 99–110, 2011.

[235] M. Firdhous, O. Ghazali, and S. Hassan, "A trust computing mechanism for cloud computing with multilevel thresholding," in *6th International Conference on Industrial and Information Systems, Kandy, Sri Lanka*, 2011, pp. 457–461.

[236] F. Ikhouane and J. Rodellar, *Systems with Hysteresis: Analysis, Identification and Control Using the Bouc-Wen Model*. John Wiley & Sons, 2007.

Universiti Utara Malaysia

[237] L. M. L. Ny and B. Tuffin, "Pricing a threshold-queue with hysteresis," in *18th IASTED International Conference on Modelling and Simulation (MS 2007), Montreal, Canada*, 2007.

[238] J. Urbano, A. P. Rocha, and E. Oliveira, "Trust evaluation for reliable electronic transactions between business partners," in *Agent-Based Technologies and Applications for Enterprise Interoperability*, ser. Lecture Notes in Business Information Processing, K. Fischer, J. Muller, and R. Levy, Eds. Berlin Heidelberg: Springer, 2012, vol. 98, pp. 219–237.

[239] M. Zaki, "Handover in a wireless local area network (WLAN)," US Patent 7 164 915, January 16, 2007.

[240] R. Dhaouadi, F. H. Ghorbel, and P. S. Gandhi, "A new dynamic model of hysteresis in harmonic drives," *IEEE Transactions on Industrial Electronics*, vol. 50, no. 6, pp. 1165–1171, 2003.

[241] E. Marilly, O. Martinot, S. B. Brezetz, and G. Delegue, "Requirements for service level agreement management," in *IEEE Workshop on IP Operations and Management, Dallas, TX*, 2002, pp. 57–62.

[242] B. Kahanwal and T. P. Singh, "The distributed computing paradigms: P2p, grid, cluster, cloud, and jungle," *International Journal of Latest Research in Science and Technology*, vol. 1, no. 2, pp. 183–187, 2012.

[243] P. V. Chauhan, "Cloud computing in distributed system," *International Journal of Engineering Research & Technology*, vol. 1, no. 10, pp. 1–8, 2012.

[244] I. Verma, "Cloud computing: A study of benefits and challenges," *International Journal of advanced studies in Computer Science and Engineering*, vol. 3, no. 7, pp. 14–17, 2014.

[245] M. Al-Roomi, S. Al-Ebrahim, S. Buqrais, and I. Ahmad, "Cloud computing pricing models: A survey," *International Journal of Grid and Distributed Computing*, vol. 6, no. 5, pp. 93–106, 2013.

[246] Z. Yao, "Understanding churn in decentralized peer-to-peer networks," PhD Thesis, Texas A&M University, USA, 2009.

[247] M. Koivisto and A. Urbaczewski, "The relationship between quality of service perceived and delivered in mobile internet communications," *Information Systems and e-Business Management*, vol. 2, pp. 309–323, 2004.

[248] M. Kafai, B. Bhanu, and L. An, "Cluster-classification bayesian networks for head pose estimation," in *21st International Conference on Pattern Recognition, Tsukuba, Japan*, 2012, pp. 2869–2872.

[249] H. Amipara, "A survey on cloudsim toolkit for implementing cloud infrastructure," *International Journal of Science Technology & Engineering*, vol. 1, no. 12, pp. 239–243, 2015.

[250] OMICS Internetaional. (2015) List of countries by Internet connection speeds. Website. OMICS Internetaional. [Online]. Available: http://research.omicsgroup.org/index.php/List_of_countries_by_Internet_connection_speeds