

A FRAMEWORK FOR MANAGEMENT OF CLOUD SERVICES

Hong Thai Tran
University of Technology Sydney

A thesis submitted to Faculty of Engineering and Information Technology
University of Technology Sydney
in fulfilment of the requirements for the thesis of
Doctor of Philosophy in Information System

2018

Certificate of Original Authorship

I certify that the work in this report has not previously been submitted for a degree nor has it been submitted as part of requirements for a degree except as fully acknowledged within the text.

I also certify that the report has been written by me. Any help that I have received in my research work and the preparation of the report itself has been acknowledged. In addition, I certify that all information sources and literature used are indicated in the report.

Production Note:

Signature of Student: Signature removed prior to publication.

Date: 10 May 2018

Acknowledgment

First, I would like to thank my principal supervisor Dr George Feuerlicht for his guidance, encouragement, enthusiasm, technical comments, and constructive criticism through all years of my research. I will extremely appreciate his full support during my study. I also would like to express my deep gratitude to my co-supervisor, Professor Didar Zowghi, for her valuable advice and guidance during my PhD study.

Special thanks to the University of Economics, Ho Chi Minh City (UEH), Vietnam International Education Development (VIED) under the Ministry of Education and Training (MoET) and University of Technology Sydney (UTS) for providing a scholarship and other financial support for my study.

To my friends, Thanh Nguyen Van, Son Nguyen Thanh and my colleagues at Vastbit, Ndex and IMT Solutions, many thanks for a vibrant, creative and exciting discussions and experiences that help me to initialize ideas in the early stage.

Dad, thanks for your love and everything you did for me. You are always in my heart and my memory. Without you, this work would not have been possible. Mum, thank for your love, encouragement, and patience to help me complete this study. Sisters, thanks a lot for your inspiration and supports. I have been incredibly fortunate to have love and support from such family.

Finally, to my wife, my daughter, and my son, thank you for besides me through years and encouraging, enduring and inspiring this work. Love you always.

Contents

Certificate of Original Authorship	3
Acknowledgment	5
List of Publications	11
List of Illustrations	13
List of Tables	15
List of Abbreviations	17
Abstract	19
Chapter 1. Introduction	21
1.1. Introduction.....	22
1.2. Problem Definitions.....	24
1.2.1. Challenges in cloud service management.....	24
1.2.2. Research Gaps.....	26
1.2.3. Research Problem	27
1.2.4. Research Questions.....	27
1.3. Key Terminologies	29
1.3.1. Enterprise Application	29
1.3.2. Cloud Service.....	30
1.3.3. Service Consumer	30
1.3.4. Service Incident	30
1.4. Scope of Work	31
1.4.1. Using Payment Service as Examples	31
1.4.2. Service Consumer Perspective.....	31
1.4.3. Using Availability and Response Time for Service Measurements	32
1.5. Research Methodology	32
1.6. Structure of the Dissertation	34
1.7. Conclusion	36
Chapter 2. Literature Review.....	37
2.1. Introduction.....	38
2.2. Background and Concepts	38

2.2.1.	Software Engineering.....	38
2.2.2.	Service Oriented Architecture.....	43
2.2.3.	Cloud Computing.....	47
2.3.	Review of Cloud SDLC.....	53
2.3.1.	ITIL Lifecycle for Cloud.....	54
2.3.2.	Extreme Cloud Programming SDLC.....	56
2.3.3.	Cloudification Security Development Lifecycle.....	57
2.3.4.	SOA Cloud Lifecycle Using Service Component Architecture.....	58
2.3.5.	The Service Lifecycle on Cloud.....	59
2.4.	Review of SDLC Phases.....	61
2.4.1.	Requirements Specification.....	62
2.4.2.	Cloud Service Identification.....	64
2.4.3.	Cloud Service Integration.....	69
2.4.4.	Cloud Service Monitoring.....	70
2.4.5.	Cloud-based Application Optimisation.....	72
2.5.	Evaluation of The Existing Work.....	73
2.6.	Conclusion.....	74
Chapter 3.	Research Methodology.....	76
3.1.	Introduction.....	77
3.2.	Research Paradigm.....	77
3.3.	Design Science.....	78
3.4.	Research Techniques and Methods.....	80
3.4.1.	Motivation Research.....	81
3.4.2.	Literature Survey.....	81
3.4.3.	Action Design Research.....	82
3.4.4.	Simulation Research.....	83
3.5.	Conclusion.....	83
Chapter 4.	Cloud Service Consumer SDLC.....	85
4.1.	Introduction.....	86
4.2.	Cloud Service Consumer System Development Lifecycle.....	87
4.3.	Requirements Specification.....	88
4.3.1.	Request for Service.....	89
4.3.2.	Functional Requirements.....	91

4.3.3.	Non-Functional Requirements	92
4.3.4.	Other Requirements	92
4.4.	Service Identification	94
4.5.	Service Integration	96
4.6.	Service Monitoring	98
4.7.	Optimisation.....	101
4.8.	Evaluation using The Case Study at Family Medical Practice.....	105
4.8.1.	Situation at FMP	105
4.8.2.	Requirements of Enterprise Application at FMP.....	106
4.8.3.	Evaluation of SC-SDLC	107
4.8.4.	Feedback of the SC-SDLC Phases.....	110
4.8.5.	Design Cycle of SC-SDLC	113
4.9.	Conclusion	115
Chapter 5.	Service Consumer Framework Implementation.....	117
5.1.	Introduction.....	118
5.2.	SCF Architecture	119
5.3.	SCF Modules	121
5.3.1.	Service Repository	122
5.3.2.	Service Adaptors.....	123
5.3.3.	Workflow Engine.....	124
5.3.4.	Monitoring Centre.....	125
5.4.	SCF Implementation	125
5.4.1.	Service Repository Implementation.....	126
5.4.2.	Workflow Engine Implementation	130
5.4.3.	Monitoring Centre Implementation	131
5.4.4.	Evaluation of SCF	134
5.4.5.	Design Cycle of SCF	136
5.5.	Conclusion	136
Chapter 6.	Failover Strategies for Improving Application Availability	138
6.1.	Introduction.....	139
6.2.	SCF Reliability Features.....	140
6.2.1.	Retry Fault Tolerance	141

6.2.2.	Recovery Block Fault Tolerance	142
6.2.3.	Dynamic Sequential Fault Tolerance.....	143
6.3.	Cloud Service Load Balancing	144
6.4.	Implementation of Reliability Strategies and Load Balancing.....	146
6.4.1.	Service Adaptors.....	146
6.4.2.	Workflow Engine.....	147
6.5.	Experimental Verification.....	148
6.5.1.	Case study of payment services	148
6.6.	Conclusion	152
Chapter 7.	Multi-Site Monitoring for Application Optimisation.....	154
7.1.	Introduction.....	155
7.2.	Multi-Site Monitoring Model	156
7.2.1.	Enterprise application optimisation strategies	158
7.3.	Experimental setup for multi-site monitoring.....	159
7.4.	Conclusion	171
Chapter 8.	Conclusion and Future Work	173
8.1.	Conclusion	174
8.2.	Future Work.....	177
Bibliography	179
APPENDIX A.	LIST OF QUALITY OF SERVICE ATTRIBUTES	188
APPENDIX B.	THE FMP BUSINESS REQUIREMENTS.....	190
APPENDIX C.	CLOUD SERVICE ADAPTOR INTERFACES.....	211
APPENDIX D.	QUESTIONNAIRE.....	223
APPENDIX E.	SOFTWARE.....	225

List of Publications

The following publications were made during this thesis study:

- [1] Feuerlicht, G. & Tran, H. T., “*Service consumer framework: Managing Service Evolution from a Consumer Perspective.*” In ICEIS-2014. 16th International Conference on Enterprise Information Systems (ICEIS), 2014, Portugal.
- [2] Feuerlicht, G. & Tran, H. T., “*Enterprise Application Management in Cloud Computing Context.*” In The 8th International Conference on Research and Practical Issues of Enterprise Information Systems (CONFENIS), 2014, Ha Noi, Vietnam. ACM. (Best Paper Award)
- [3] Feuerlicht, G., Tran, H. T., “*Adapting Service Development Lifecycle for Cloud,*” In The 17th International Conference on Enterprise Information Systems (ICEIS), 2015, Spain
- [4] Tran, H. & Feuerlicht, G., “*Service Repository for Cloud Service Consumer Lifecycle Management.*” in The European Conference on Service-Oriented and Cloud Computing (ESOCC), 2015, Taormina, Italy, Springer, 171-180.
- [5] Tran, H. & Feuerlicht, G., “*Service Development Life Cycle for Hybrid Cloud Environments,*” Journal of Software, 2016.
- [6] Tran, H. & Feuerlicht, G., “*Improving Reliability of Cloud-based Applications.*” in The European Conference on Service-Oriented and Cloud Computing (ESOCC), 2016, Vienna, Austria, Springer.
- [7] Tran, H. & Feuerlicht, G., “*Optimization of Cloud Applications Using Location-Based QoS Information.*” In The 10th International Conference on Research and Practical Issues of Enterprise Information Systems (CONFENIS), 2016, Vienna, Austria, Springer.

List of Illustrations

Figure 1.1. Cloud service oriented enterprise application	29
Figure 1.2. The overview of research methodology	32
Figure 1.3. Thesis structure and organisation	33
Figure 2.1. Traditional SDLC (Papazoglou, 2008)	45
Figure 2.2. Cloud service model and management levels (Walton, 2016)	49
Figure 2.3. The conceptual reference model (Liu et al., 2011)	52
Figure 2.4. The ITIL service lifecycle (ITIL, 2014)	54
Figure 2.5. Extreme cloud programming SDLC on cloud computing (Guha, 2013).....	56
Figure 2.6. Cloudification security development lifecycle (Wagner et al., 2015)	57
Figure 2.7. SOA cloud lifecycle using SCA (Ruz et al., 2011)	58
Figure 2.8. SOA cloud lifecycle using SCA (Joshi et al., 2014)	60
Figure 2.9. Requirements engineering activities (Cemuturi, 2014)	62
Figure 2.10. Service selection system architecture (Tang et al., 2017)	65
Figure 3.1. Design science research cycles (Hevner, 2007)	78
Figure 3.2. Overview of FMP	82
Figure 4.1 Cloud Service Consumer SDLC and lifecycle activities	88
Figure 4.2. AWS EC2 server monitoring at the provider side	98
Figure 4.3. Airport pick-up service optimisation scenario.....	101
Figure 4.4. Business process optimisation example.....	103
Figure 4.5. Technical optimisation example	104
Figure 4.6. The deployment diagram of FMP application (Nguyen, T., 2017)	107
Figure 4.7. The first version of SC-SDLC	114
Figure 4.8. The second version of SC-SDLC	114
Figure 5.1. SCF architecture	119
Figure 5.2. SCF modules.....	121
Figure 5.5. Service Repository user interface for cloud service selection.....	127
Figure 5.6. Service Repository entity relationship diagram.....	128
Figure 5.7. Workflow Engine and Service Adaptor implementation.....	130
Figure 5.8. Monitoring Center implementation	132

Figure 5.9. QoS analysis entity relationship diagram	133
Figure 5.10. Monitoring Centre user interface.....	134
Figure 5.11. The first version of SCF	136
Figure 6.1. Retry Fault Tolerance	141
Figure 6.2. Recovery Block Fault Tolerance	142
Figure 6.3. Online shopping scenario using a composite payment service	143
Figure 6.4. Dynamic Sequential Strategy	144
Figure 6.5. Cloud service load balancing.....	144
Figure 6.6. Service Consumer Framework reliability features	146
Figure 6.7. Experimental configuration	148
Figure 6.8. Availability of reliability strategies from 15th to 31st of March.....	151
Figure 6.9. Availability of reliability strategies from 1 st to 15 th of April 2016.....	152
Figure 7.1. Online shopping check out optimisation scenario	156
Figure 7.2. Multi-site cloud service monitoring	157
Figure 7.3. Daily average response times of eWay and PayPal services.....	167
Figure 7.4. Daily average availability of eWay and PayPal services.....	171

List of Tables

Table 2.1. Advantages and disadvantages of the traditional SDLC.....	41
Table 2.2. Comparison of cloud models.....	51
Table 2.3. Cloud service identification approaches	68
Table 4.1. Request for Service for online payment.....	90
Table 4.2. Requirement specification priority levels	93
Table 4.3. Requirement specification importance levels	93
Table 5.1. SCF modules implementation	126
Table 6.1. Suitability of reliability strategies	145
Table 6.2. Payment service transaction logs	150
Table 6.3. Availability of payment services.....	150
Table 6.4. Response time of payment services in seconds.....	151
Table 7.1. QoS data for eWay and PayPal payment services	160
Table 7.2. Response time and availability correlation coefficients.....	162
Table B.1. List of QoS attributes (Meier et al., 2009).....	188

List of Abbreviations

CTO	Chief Technology Officer
DFST	Dynamic Sequential Fault Tolerance
ERD	Entity Relationship Diagram
ESB	Enterprise Service Bus
FT	Fault Tolerance
IaaS	Infrastructure as a Service
IoT	Internet of Things
IT	Information Technology
ITIL	Information Technology Infrastructure Library
MSSQL	Microsoft SQL Server
NIST	National Institute of Standards and Technology
PaaS	Platform as a Service
QoS	Quality of Service
RBFT	Recover Block Fault Tolerance
RE	Requirements Engineering
REST	Representational State Transfer
RFS	Request for Service
RFT	Retry Fault Tolerance
SaaS	Software as a Service
SBA	Service-based application
SCA	Service Component Architecture
SCF	Service Consumer Framework
SC-SDLC	Service Consumer System Development Life Cycle
SDLC	System Development Life Cycle
SLA	Service Level Agreement

SOA	Service Oriented Architecture
SOAP	Simple Object Access Protocol
SOC	Service-Oriented Computing
UML	Unified Modelling Language
XaaS	Everything as a Service
XML	Extensible Markup Language

Abstract

The rapid growth of various types of cloud services is creating new opportunities for innovative enterprise applications. Organisations are using cloud services to deliver significant parts of their enterprise system instead of on-premises implementation. However, existing traditional software engineering lifecycle models are not adequate in the cloud context, and a comprehensive framework for managing cloud services from the consumer perspective throughout all phases of the lifecycle has not been fully described in the literature. This thesis addresses the following key research questions: “What lifecycle methodology should be used by cloud service consumers?” and “What framework is required to support this lifecycle methodology?”

To address these research questions, this thesis is concerned with how to develop cloud service-oriented enterprise applications from the service consumer perspective. For the purposes of this work, a cloud system development lifecycle is proposed, and a supporting framework is developed. This research also aims to expand the understanding of the challenges of using cloud services in enterprise application management. The main contributions of this thesis are the Service Consumer System Development Lifecycle (SC-SDLC), the Service Consumer Framework (SCF), a set of failover strategies for improving application reliability and a multi-site monitoring model for managing cloud services proactively. The SC-SDLC is the cloud lifecycle that is used to develop cloud service-oriented enterprise applications. Supporting the SC-SDLC activities, the SCF is implemented to manage cloud services from the consumer perspective. The failover strategies are designed to handle the problems of service disruptions, and the multi-site monitoring model is designed to monitor cloud services for the purposes of service selection and application optimisation.

Using a research approach based on design science and action research, the SC-SDLC and SCF are the results of an iteration process between the core activities of building and evaluating using a case study. By working closely with the team members of a *real-world* project for developing a hospital management system, the lifecycle activities and the framework features are being continuously improved during the project execution phase.

Additionally, to evaluate the failover strategies, a simulation environment is set up to provide a comparison of the theoretical calculation results with the experimental measurements. A separate simulation environment is also used to demonstrate the applicability of the multi-site monitoring model in selecting cloud services and application optimisation.