UNIVERSITI PUTRA MALAYSIA

SELF-HEALING FRAMEWORK FOR SERVICE LEVEL AGREEMENT MONITORING AND VIOLATION REACTING IN CLOUD COMPUTING

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By

AHMAD MOSALLANEJAD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfillment of the Requirement for the Degree of Doctor of Philosophy

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DEDICATION

This thesis is especially dedicated to my wife and parents.

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

SELF-HEALING FRAMEWORK FOR SERVICE LEVEL AGREEMENT MONITORING AND VIOLATION REACTING IN CLOUD COMPUTING

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December 2014

Chairman: Associate Professor Rodziah Atan, Ph.D.

Faculty: Computer Science and Information Technology

Service Level Agreement (SLA) is a mutual contract between service provider and consumer upon quality of service in cloud computing. A self-healing framework is unavoidable to monitor the agreed services and react against any probable SLA violation. Some SLA-based self-healing frameworks are presented but the rate of SLA violations is significantly high. Current SLA structure is not adapted for the hierarchical nature of SLAs in cloud computing. The response time of SLA monitoring systems also are not fast enough for early violation detection, and consuming a high overhead cost for bandwidth, CPU and memory consumption in both server and virtual machine sides. High reaction time for recovering violated services is also a considerate issue in this matter. Consequently, cloud consumers faced significant number of SLA violations in their services. The critical literature review conducted by this study highlighted the mentioned problem statements in detail.

In this study, an extended SLA is proposed to fulfill the hierarchical structure of SLAs in cloud computing. The objective of self-monitoring SLA is mainly to reduce the monitoring response time and overhead. A self-healing framework is also proposed to reduce the reviving time for violated services. The proposed framework is developed based on self-monitoring SLA as to reduce the rate of SLA violations.

The self-healing framework is evaluated by two different experiment scenarios in cloud computing. The proposed self-monitoring SLA and LoM2HiS, as a related work, are developed in the first experiment. Both of monitoring systems are executed to monitor virtual machines based on predefined SLA with the number of virtual machines increases from 1 to 4 units. The response time, bandwidth, CPU and memory consumption of monitoring systems are recorded and observed at run time. As for the second experiment, SLA1 and SLA2 are defined for *hMailServer* and SQL

Database services respectively while SLA1 is depended on SLA2. The proposed self-healing framework and three other alternative works are developed to keep *hMailServer* and SQL Server available. The implemented frameworks are executed in described scenario for 20 minutes and every 5 minutes an intrusion attack applied to stop SQL service. The reaction speed and the rate of SLA violation are measured in this experiment for results comparison.

The response time of self-monitoring SLA is recorded to be seven times less than LoM2HiS. The average reviving time in self-healing framework is recorded to be two times lesser than developed related work based on LoM2HiS. The self-healing SLA also decreased the number of SLA violations. Therefore, the proposed self-healing framework is proven to reduce the overhead of SLA monitoring and the number of SLA violations in cloud computing. The proposed system has also been executed in real environment for validation purposes.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia
sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

RANGKA KERTA SLA PULIH-DIRI UNTUK PEMANTAUAN TAHAP PERJANJIAN PERKHIDMATAN DAN TINDAK BALAS PELANGGARAN DALAM PERKOMPUTERAN AWAN

Oleh

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Sejak kebelakangan ini, terdapat beberapa rangka kerja penyembuhan diri (*self-healing*) berdasarkan perjanjian tahap perkhidmatan (*service level agreement* (SLA)) telah banyak dibentangkan malangnya ia masih tidak dapat memenuhi keperluan perkomputeran awan (*cloud computing*) secara efektif. Struktur SLA semasa adalah tidak bersesuaian dengan sifat hirarki semulajadi yang terdapat di dalam perkomputeran awan. Tambahan pula, masa tindak balas yang diperlukan oleh pemantauan sistem SLA tidak mencukupi untuk tindak balas pelanggaran awal, serta ia mempunyai kos overhed yang tinggi termasuklah jalur lebar, CPU dan penggunaan memori di dalam kedua-dua mesin pelayan dan maya. Tambahan pula, sistem penyembuhan diri ini memerlukan masa reaksi yang tinggi untuk pulih daripada perkhidmatan perlanggaran. Akibatnya, pengguna awan berdepan dengan bilangan SLA yang signifikan semasa pelanggaran. LoM2HiS ialah merupakan rangka kerja pemantauan SLA dan QU4DS ialah rangka kerja jaminan qualiti perkhidmatan (*quality of service* (QoS) yang telah dibentangkan dan dinyatakan permasalahannya. Kajian literatur yang sistematik telah ditekankan dalam pernyataan masalah ini.

Dalam kajian ini, dilanjutkan SLA telah dicadangkan sebagai SLA lanjutan yang bertujuan untuk memenuhi sifat hirarki SLA yang terdapat dalam perkomputeran awan. Tambahan, framework penyembuhan diri SLA telah dicadangkan dengan tujuan untuk mengurangkan masa pemantauan tindak balas dan overhed. Tambahan pula, framework konsep penyembuhan diri telah dicadangkan dengan tujuan untuk mengurangkan masa pemulihan yang diperlukan dari melanggar perkhidmatan. Akhirnya, penyembuhan diri SLA telah dibangunkan berdasarkan SLA lanjutan dan penyembuhan diri SLA yang dicadangkan untuk mengurangkan kadar pelanggaran SLA.

Penyembuhan diri SLA ini dinilai daripada dua senario eksperimen dalam perkomputeran awan. Penyembuhan diri SLA yang dicadangkan dan LoM2HiS, sebagai kerja-kerja berkaitan, dibangunkan di dalam eksperimen yang pertama. Kedua-dua sistem pemantauan ini dijalankan untuk memantau mesin maya berdasarkan SLA yang telah ditetapkan di mana bilangan mesin maya bertambah daripada 1 unit kepada 4 unit. Masa tindak balas, jalur lebar, CPU dan penggunaan memori oleh sistem pemantauan ini dipantau pada masa ianya berjalan. Dalam eksperimen yang kedua, SLA1 dan SLA2 ditakrifkan untuk hMailServer dan perkhidmatan pangkalan data SQL di mana SLA1 bergantung kepada SLA2. Penyembuhan diri SLA yang dicadangkan dan tiga alternatif yang lain telah dibangunkan untuk menyimpan hMailServer dan pelayan SQL yang sedia ada. Penyembuhan diri SLA telah dijalankan dalam senario yang telah diterangkan dalam masa 20 minit dan setiap 5 minit serangan pencerobohan digunakan untuk menghentikan perkhidmatan SQL. Reaksi tindak balas dan kadar perlanggaran SLA dalam eksperimen ini diukur dengan tujuan untuk membandingkan penyembuhan diri SLA dengan kerja-kerja yang berkaitan.

Keputusan menunjukan bahawa penyembuhan diri SLA yang dicadangkan telah menggunakan jumlah jalur lebar yang agak sama dengan kerja-kerja yang berkaitan tetapi ia mampu menambah baik semua pemboleh ubah yang lain. Masa tindak balas bagi kedua-dua penyembuhan diri SLA dan LoM2HiS meningkat apabila bilangan mesin maya meningkat tetapi masa tindak balas penyembuhan diri SLA adalah 7 kali kurang daripada LoM2HiS. Disamping itu, purata masa pemulihan dalam penyembuhan diri SLA adalah 2 kali kurang daripada kerja yang berkaitan dan penyembuhan diri SLA boleh juga mengurangkan jumlah perlanggaran SLA. Oleh itu, framework penyembuhan diri yang dicadangkan berkesan mengurangkan overhed dan pelanggaran dalam pengkomputeran awan.

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

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LIST OF ABBREVIATIONS

DSL	Domain Specific Language
IDeC	InfoComm Development Center
SLA	Service Level Agreement
SLO	Service Level Objective
MAPE	Monitoring, Analyzing, Planning and Executing
IaaS	Infrastructure as a Service
PaaS	Platform as a Service
SaaS	Software as a Service
SH-SLA	Self-healing SLA
QoS	Quality of Service
VM	Virtual Machine
VO	Virtual Organization
SLAMS	SLA Monitoring System
WS	Web Service
WSLA	Web Service Level Agreement
WSML	Web Service Management Language
WPC	Windows Performance Counter

CHAPTER 1

INTRODUCTION

1.1 Background

Service level agreement (SLA) is a mutual contract between service provider and consumer in cloud computing (Rimal *et al.*, 2011). Service providers have to upload services based on agreed service level objective (SLO) (Gómez *et al.*, 2011; Stiller, 2011). Service providers commonly face unexpected risks in cloud environment which can become a threat to SLO. The SLA violation is exceeding of quality of service (QoS) value from the agreed SLO (Wu and Buyya, 2011). Due to this, a self-healing framework is unavoidable to monitor the agreed services and react against any probable SLA violations to revive the services quickly (Comuzzi *et al.*, 2012; Dai *et al.*, 2009).

The self-healing framework includes monitoring, analysis, planning, and execution (MAPE) processes which can be divided in monitoring and reacting modules (Maurer *et al.*, 2011; Psaier and Dustdar, 2011; Weyns *et al.*, 2013). The SLA monitoring is the verification of any changes in QoS value periodically (Buco *et al.*, 2004). The monitoring module should collect data from running service and compare the actual service quality with stated attribute in SLA (Mazur *et al.*, 2011). If the value of service quality exceeds from agreed value in SLA, a violation is happening and the reaction should take place. The reaction module should first choose the suitable reaction plan then apply the actions to the cloud infrastructure for reviving the service (Maurer *et al.*, 2013). The SLA violation reaction can be either by internal resources rearrangement or by external resource invocation (Psaier and Dustdar, 2011). In describing self-healing framework, the overhead of SLA monitoring process, the needed time for reviving the services and the amount of SLA violations should be minimized (Emeakaroha *et al.*, 2012c; Freitas *et al.*, 2010).

SLAs in cloud computing usually have hierarchical connections during upstream and downstream cloud layers (Katsaros *et al.*, 2012) including infrastructure as a service (IaaS), platform as a service (PaaS) and software as a service (SaaS) (Dillon *et al.*, 2010). There are various SLAs between clients and providers, in these layers some of them depend on each other (Ul Haq and Schikuta, 2010). If the specific SLA in the lower layer is violated then its dependent SLAs in the upper layer will be violated as well (Haq *et al.*, 2010a). So, normally SLAs depend on each other in cloud computing environment hierarchically.

1.2 Problem Statement

The infrastructure of a Cloud is very complex. This complexity translates into more effort needed for management and monitoring. The greater scalability and larger size of Clouds compared to traditional service hosting infrastructures, involve more complex monitoring systems, which have therefore to be more scalable, robust and fast. Such systems must be able to manage and verify a large number of resources and must do it effectively and efficiently. This has to be achieved through short

measurement times and fast warning systems, which are able to quickly spot and report performance impairments or other issues, ensuring timely interventions such as the allocation of new resources (Aceto *et al.*, 2013). The response time and consumed resources by monitoring framework are defined as the evaluation criteria for assessing the performance of monitoring frameworks (Emeakaroha *et al.*, 2010a; Emeakaroha *et al.*, 2012c). The experiment results of the SLA monitoring framework by Emeakaroha et al. (2010a; 2012c), LoM2HiS, has illustrated high response time and overhead cost of monitoring process.

A few studies focused on both SLA monitoring and violation reacting process to propose a healing framework for cloud computing. The main related works, consisting QU4DS (Freitas *et al.*, 2010) and LoM2HiS (Emeakaroha *et al.*, 2012a), engaged the MAPE loop to react against violations and reduce the rate of SLA violations. The evaluation result of QU4DS, as a self-healing system, has presented significantly increased rate of unsuccessful reactions for reviving the SLA violations (Freitas *et al.*, 2010). The healing frameworks have high reviving time and significant rate of SLA violations in cloud computing.

Several studies have illustrated the need of hierarchical relation among SLAs in cloud environments (Comuzzi *et al.*, 2009; Haq *et al.*, 2010b; Ul Haq *et al.*, 2009) while the basic structure of SLA is not compatible for this kind of relationships. Current structure of SLA is unable to record the list of dependent SLAs and it makes a delay in bottom-up propagation of failures to the layer of cloud. Subsequently, the reaction is activated after significant delay and it increases service degradation (Katsaros *et al.*, 2012).

Chapter 2 illustrated the current state of SLA monitoring and self-healing frameworks in cloud computing and critical review of related works highlighted the above problem statements.

1.3 Objectives

The main research objective is a self-healing framework to reduce the degradation of agreed service and, in other words, reduce the rate of SLA violations in cloud computing. In order to achieve the main research objective, this research has taken up some preliminary exercises. First, a self-healing SLA framework is proposed to reduce the reviving time and amount of SLA violations. Second, the SLA structure is extended to fulfill the hierarchical relation of SLAs in cloud computing. The extended SLA accelerates and simplifies the propagation of detected violations between depended service providers. Third, the extended SLA is employed to design a self-monitoring system to reduce the response time and overhead cost for SLA monitoring activities.

1.4 Contributions

The main contributions of this study consist 1) The development and evaluation of the proposed self-healing SLA framework based on experiment and actual testbed. 2) The extension of SLA structure through “relation” and “function” parts strategy that is added to the normal structure of SLA. 3) The development of SLA self-monitoring system by employing the proposed extended SLA.

1.5 Research Scope

Figure 1.1 illustrates the life cycle of SLA from SLA negotiation up to SLA expiration. The SLA is contracted after SLA negotiation between service provider and consumer. Next, the agreed service is deployed and is monitored periodically. If any SLA violation is detected, the reaction can be applied to revive the service. Then, the SLA report can show the quality of service and the number of violations. Finally, the agreed service is terminated when the SLA duration is expired.

Figure 1.1. The life cycle of SLA (Faniyi and Bahsoon, 2012)

The research scope is presented in the dotted area of Figure 1.1. This study is limited to SLA monitoring and violation reacting as a main parts of self-healing system. The SLA negotiation and service deployment issues are not covered as a part of this research. So, a predefined SLA and cloud services are assumed for research experiment. The presented SLA lifecycle is common in public cloud and experimental scenarios are also defined based on service provisioning in public cloud.

1.6 Thesis Organization

The thesis is organized based on the standard structure of thesis and dissertations at University Putra Malaysia. It is organized in a manner to give detail information on how the research is carried out. As the final report of this research, this thesis consists of six chapters.

The first chapter of the thesis, which is an introductory chapter, introduces the motivation and background of the research. Next, the problem statement and objectives of research are highlighted. The scope and the research contributions are also presented in this chapter.

Chapter 2 is the Literature Review that provides a review and discussion of past works relevant to this research. In this chapter, the related works about SLA structure, hierarchical SLA and self-healing framework are discussed based on published resources such as journals, conference proceedings and seminars.

Next is Chapter 3 which is called Research Methodology. This chapter justifies the research methodology design employed in conducting this research. The methodology consists of the experiment scenario, testbed setup and data collection method for both self-monitoring SLA and self-healing framework evaluation. The experiment tools and analysis method also explained in Chapter 3.

Following Chapter 3, the proposed framework and SLA extension are described in Chapter 4. In this chapter, the hierarchical SLAs of cloud computing are illustrated based on extended SLA. The proposed self-healing framework, adapted rule-based reaction method and self-monitoring SLA process are also described. The implementation of self-monitoring system and self-healing framework are presented in Chapter 5.

Chapter 6 describes the research findings and discusses about the experiment results. Collected data of self-monitoring and self-healing SLA are compared with developed related works.

The final and conclusion chapter of the thesis is Chapter 7. The conclusion of the research and its limitations, as well as potential future research is all presented in this chapter. Figure 1.2 presents the map of thesis chapters and their connections.

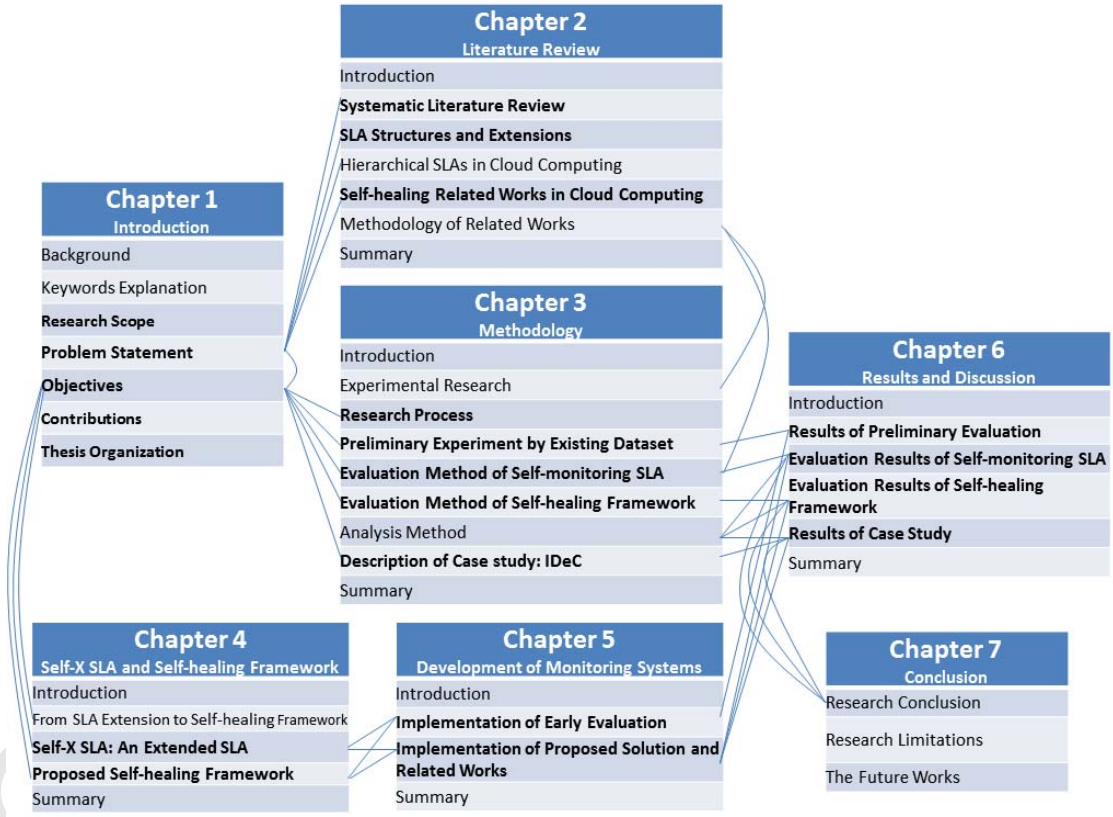

Figure 1.2. The map of thesis chapters and their connections

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