

COLLABORATIVE-BASED DECISION MAKING FOR WEB SERVICE  
COMPOSITION USING SERVICE LEVEL AGREEMENT  
NEGOTIATION AND CROWDSOURCING

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To our prophet, *Mohammad*, the messenger of truth, fraternization and kindness

To my dear and beloved *wife* who encouraged and supported me

To my dears *mother, father, and sister*

To my dears *mother-, father-, brothers- and sisters-in-law*

And to all who supported me in my study, especially my *supervisor*

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## ABSTRACT

Quality of Service (QoS)-aware Web Service Composition as complex problem solver has become one of the most highlighted issues in service computing area. It maps to multi-objective optimization problem that is classified as Non-deterministic Polynomial-time hard (NP-hard) problem. The diversity of subjective and potentially dishonest evaluations impose an obstacle to QoS-aware service assessment. The vague preferences of users have also to be considered in multi-criteria service selection. Last but not least, the budget-constrained service negotiation needs to make trade-off between the desired QoS metrics and the imposed budget constraints by service users. There is a large body of research covering aforementioned different aspects of service composition. This research tries to open a new horizon for service composition to utilize collaborative decision support systems. The proposed system involves three phases, namely Trust-Aware Crowd-enabled consensus-based Service Assessment (TACSA), Fuzzy inference-based multi-criteria Service Ranking (FASER), and Pareto-optimal service composition (PALEN). In the first phase, TACSA is responsible to assess all candidate services with respect to the required QoS metrics and guarantee this assessment not to suffer from subjective and dishonest evaluations by means of the collaborative decision making. The incurred complexity in capturing users' preferences and objectives is the second obstacle to rank services. FASER, the fuzzy inference engine, is then used to capture user preferences and support multi-criteria QoS-based service ranking. After that, the composer is required to negotiate with ranked service providers and select the best-possible candidate service based on users' QoS desires and constraints. PALEN enables composer to achieve this aim using the autonomous service level agreement negotiation strategy and surplus management. The focus of the proposed negotiation strategy is restricted to the time-dependent tactic that can handle the deadline imposed by users. Besides, a novel approach proposed to dynamically adjust time-dependent function parameter based on service demand and utilization, and redistribute surplus to optimize the composite service. The research promises to select the best candidate services that maximizes QoS metrics while adheres to users' budget constraints. The extensive experimental results along with simulated scenarios demonstrate the applicability and effectiveness of the proposed approach. It is interesting to note that the consensus on assessed QoS metrics is achieved with respect to different parameters and the crowd converge to the most trustworthy service assessment. Moreover, the results indicate that the composition optimality is averagely increased by almost 80% considering different composition scenarios.

## ABSTRAK

Komposisi Perkhidmatan Web Kesedaran Kualiti Perkhidmatan (QoS) sebagai penyelesaian masalah yang kompleks ialah salah satu isu yang sering diketengahkan dalam bidang pengkomputeran servis. Ia dipetakan kepada masalah optimasi pelbagai objektif yang diklasifikasikan sebagai masalah Masa-Polinomial Tidak-berketentuan (NP-hard). Kepelbagaian subjektiviti dan potensi penilaian tidak jujur memberi halangan kepada penilaian servis kesedaran kualiti perkhidmatan. Kekaburan dalam keutamaan para pengguna mesti diambil kira dalam pemilihan servis pelbagai-kriteria. Akhir sekali, servis rundingan yang dikekang oleh faktor bajet diperlukan untuk menyeimbangkan metrik kualiti perkhidmatan yang diperlukan, dan kekangan bajet yang ditetapkan oleh pengguna servis. Terdapat banyak penyelidikan yang meliputi aspek berbeza dalam komposisi perkhidmatan. Penyelidikan ini meneroka perspektif baru supaya komposisi perkhidmatan dapat menggunakan sistem sokongan keputusan kolaboratif. Sistem yang dicadangkan melibatkan tiga fasa iaitu, Taksiran Perkhidmatan Kesedara-Keselamatan Berkebolehan Ramai Berasaskan Konsensus (TACSA), Pemangkatan Perkhidmatan Berbilang-Kriteria Berasaskan Inferen Kabur (FASER), dan Komposisi Perkhidmatan Optimum-Pareto (PALEN). Pada fasa pertama, TACSA bertanggungjawab menilai semua calon perkhidmatan berdasarkan metrik kualiti perkhidmatan yang diperlukan dan menjamin penilaian ini tidak melalui penilaian subjektif dan yang tidak jujur dengan menggunakan keputusan kolaboratif. Kompleksiti terkumpul semasa mendapatkan pilihan pengguna dan objektif ialah rintangan kedua untuk mengklasifikasikan perkhidmatan. FASER, enjin inferens kabur digunakan untuk merekod pilihan pengguna dan menyokong kedudukan perkhidmatan pelbagai kriteria berasaskan kualiti perkhidmatan. Komposer diperlukan untuk berunding dengan pembekal perkhidmatan yang telah disusun kedudukannya dan memilih calon perkhidmatan terbaik berdasarkan kualiti perkhidmatan dan kekangan pengguna. PALEN membolehkan komposer mencapai tujuan ini menggunakan strategi perundingan autonomi perjanjian aras servis dan pengurusan lebihan. Fokus strategi rundingan yang dicadangkan terhad kepada taktik kebergantungan kepada masa yang boleh mengendalikan tarikh akhir yang ditetapkan pengguna. Selain itu, pendekatan baru diperkenalkan untuk menyesuaikan secara dinamik parameter fungsi berasaskan masa, berdasarkan perkhidmatan permintaan dan penggunaan, dan pengagihan lebihan untuk mengoptimasikan perkhidmatan komposit. Penyelidikan ini menjanjikan pemilihan calon perkhidmatan terbaik yang dapat memaksimumkan metrik kualiti perkhidmatan dan dalam masa yang sama mematuhi kekangan bajet pengguna. Keputusan eksperimental yang banyak bersama senario yang disimulasikan menunjukkan kesesuaian dan keberkesanan pendekatan yang dicadangkan. Yang menarik, konsensus ke atas metrik kualiti perkhidmatan yang dinilai dapat dicapai mengikut parameter-parameter yang berbeza dan kebanyakannya tertumpu kepada penilaian servis yang paling dipercayai. Lebih-lebih lagi hasil yang didapati menunjukkan optimaliti komposisi secara purata bertambah sehingga hampir 80% dengan mengambil kira senario komposisi yang berbeza.

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## LIST OF SYMBOLS

$N$	-	Number of peers (experts or monitoring services)
$x_i$	-	Decision value (evaluation of QoS criteria)
$k$	-	Number of iteration
$\varepsilon$	-	Consensus step size
$u_i$	-	Normalized sum of signals entity $i$ receives from its trustworthy neighbors
$\Delta_i$	-	Weighted degree of all received signals by entity $i$
$T_{ij}$	-	Pair-wise trust between entity $i$ and entity $j$
$N_i$	-	Set of first-neighbours of entity $i$
$z_{ij}$	-	Collaboration Willingness between entity $i$ and entity $j$
$\delta_{ij}(k)$	-	Disagreement distance between entity $i$ and entity $j$
$z_{ij}^r$	-	Set of last $r$ movement toward an agreement from entity $i$ to entity $j$
$\tau$	-	Number of tolerable observations before trust destruction
$c$	-	Number of favourable observations before full trust achievement
$\hat{T}_j$	-	Trustworthiness of entity $j$
$\bar{T}$	-	Overall network trust indicates the strength of consensus
$a, b$	-	Negotiation Parties
$x_i$	-	Defines the range of value for an issue $i$
$\min_i^a$	-	Minimum acceptable (most preferred) value of issue $i$ for a
$\max_i^a$	-	Maximum acceptable (least preferred) value of issue $i$ for a
$V_i$	-	Offer value for issue $I$

UV	-	Utility value of the offer
$W_i$	-	Importance of issue i
$t_{\max}$	-	Negotiation deadline
$x_{b \rightarrow a}^{t_k}[i]$	-	The offer a received from b at time $t_k$ for issue i
$x_{a \rightarrow b}^{t_{k+1}}[i]$	-	The counter offer a sent to b at time $t_{k+1}$ for issue i
$\alpha_i^a(t)$	-	Time dependent decision function of issue i for a
$\beta$	-	Convexity degree
$k_i^a$	-	Initial offer value for issue i by a
$SP_j^t$	-	Price of a service j at t
$\alpha SP_j$	-	Time dependent function for price of service j
ISP <sub>j</sub>	-	Initial price offer for service j
$\beta_j$	-	Convexity degree for price of service j
$R_j$	-	Current number of utilization requests for service j
$\hat{R}_j$	-	Expected number of utilization requests for service j
CF	-	Conceding factor
DL	-	Desirability level to reach an agreement
SUX	-	Service utilization oriented tactic
Px	-	Preferences oriented tactic
SDx	-	Service demand oriented tactic
SIx	-	Service importance oriented tactic
$D_j, \hat{D}_j$	-	Current and expected demands for service j
S	-	Service
Nm	-	Service Name
Sp	-	Service Provider
$T_{\text{request}}$	-	Indicates the time when the request is sent or delegated to a service
$T_{\text{response}}$	-	Indicates the time when the corresponding response is received

$n$	-	The number of nodes (experts)
$n(\text{SReq})$	-	Number of successful served requests
$n(\text{FReq})$	-	Number of failed served requests
$Q_i(s)$	-	QoS attribute of a service $S$
$Q_i^{\min}$	-	Minimum values of the QoS attribute,
$Q_i^{\max}$	-	Maximum values of the QoS attribute
$MS_k$	-	Monitoring service
$E_I$	-	Interactions between peers
$E_T$	-	Trust relations among peers
$d$	-	The density of network (crowd)
$CS$	-	The consensus strength
$\mathcal{T}_{\text{Cov}}$	-	The convergence time
$\mathcal{D}_{\text{cov}}$	-	The convergence degree
$\vartheta_d$	-	The difference threshold
$CV_{\text{BC}}$	-	Coefficient of variations of crowd member's assessments before consensus
$CV_{\text{AC}}$	-	Coefficient of variations of crowd member's assessments after consensus
$\sigma$	-	The standard deviation of variant assessments
$\mu$	-	The mean of variant assessments
$\tau$	-	Tolerance
$c$	-	Confirmation
$\max_i^{\text{PNS}_n}$	-	Maximum value of last-ranked candidate service providers for each component service
$\max_i^{\text{PNS}_1}$	-	Maximum value of top-ranked candidate service providers for each component service
$CF$	-	Conceding Factor
$k$	-	Initial Offer

- NSO - Normalized Social Optimality
- $UV_{CS}$  - Utility value of Component Service
- $UV_{SP}$  - Utility value of Service Provider

**LIST OF ABBREVIATIONS**

AHP	-	Analytical Hierarchy Process
ANP	-	Analytic Network Process
BPEL	-	Business Process Execution Language
CSP	-	Composite Service Provider
COOP	-	Composition Optimality
CS	-	Consensus Strength
CNS	-	Component Negotiation Service
CF	-	Conceding Factor
CDSS	-	Collaborative Decision Support System
COPS-SLS	-	Common Open Policy Service for Service
CS	-	Cold Start
CF	-	Collaborative Filtering
CPC	-	Constrained Pearson Correlation
DSS	-	Decision Support System
FLC	-	Fuzzy Logic Controller
GDSS	-	Group-based Decision Support System
ICE	-	Integrated Collaborative Environment
IOS	-	Internet of Services
IOT	-	Internet of Things
KB	-	Knowledge Base
MDSS	-	Multi Participant Decision Support System
MCDM	-	Multi Criteria Decision Making

MUAT	-	Multi Attribute Utility Making
NSS	-	Negotiation Support System
NSO	-	Normalized Social Optimality
OLAP	-	Online Analytical Processing
OD	-	Optimal Distance
PALEN	-	Pareto Optimal Service Composition
PDP	-	Policy Decision Point
PCC	-	Pearson Correlation Coefficient
QoS	-	Quality of Service
RCM	-	Relational Clustering based Collaborative Filtering Model
RT	-	Response Time
REST	-	Representation State Transfer
SOC	-	Service Oriented Computing
SLA	-	Service Level Agreement
SOA	-	Service Oriented Architecture
SOAP	-	Simple Object Access Protocol
SC	-	Strongly Connected
SAW	-	Simple Additive Weighting
SPS	-	Specialized Property Search
TR	-	Associated Trust value of Response Time
TC	-	Associated Trust value of Success Rate
TACSA	-	Trust-Aware Crowd-Enabled Consensus-based Service Assessment
URL	-	University Resource Locator
URI	-	University Resource Identifier
UDDI	-	Universal Description and Integrity
WOT	-	Web of Things



WSDL	-	Web Service Description Language
WSMS	-	Web Service Management System
WSC	-	Web Service Composition
WS-CDL	-	Web Service Choreography Description Language
WS-Security	-	Web Service Security
WS-Trust	-	Web Service Trust
WS-Federation	-	Web Service Federation
XML	-	eXtensible Markup Language

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## CHAPTER 1

### INTRODUCTION

#### 1.1 Overview

Service Oriented Computing (SOC) is a dominant technology in software development and Internet-based applications that presents distinctive experiences and opportunities to service users. Their daily life is made easy because SOC brings comfort to a variety of their desired tasks and jobs by introducing progressive concepts, such as e-commerce, e-science, and e-health services. Moreover, SOC offers a brilliant opportunity for enterprises to maximize their profits and reduce their costs. It lets enterprises grow and still do not strain them financially.

The SOC paradigm is undeniably grounded on the Web service technology as its preferred delivery method (Bouguettaya *et al.*, 2014b). Web services have evolved over the years and paved the way to modern software development. Advent of Web service technology enables enterprises to make their internal business processes accessible via the Internet. Nowadays, giant IT services companies such as Google, Facebook, Twitter, and Amazon offer access to their resources and services utilizing Web services such that they can reuse and compose. According to recent seedka report (Web service search engine available at [www.seekda.com](http://www.seekda.com)), 28,606 Web services are available offered by 7739 different service providers on the Web in the context of e-tourism.

Moreover, the statistics published by several Web services publication websites e.g., *WebServiceList* (available at <http://www.webservicelist.com>), *ProgrammableWeb* (available at <http://www.programmableweb.com>), and *WSIndex*

(available at <http://www.wsindex.org>) prove that digital world have witnessed an exponential increase in Web services usage and popularity over the past few years. This trend is being accelerated via the rapid adoption of new computing paradigms such as social networks, cloud computing, and Web of Things (WoT) (Bessis *et al.*, 2012; Bouguettaya *et al.*, 2014a; Qiang *et al.*, 2012). Thus, Web services will evidently continue to play a significant role for those new emerged paradigms.

However, an atomic or elementary service (Sheng *et al.*, 2002) may not satisfy users' goals. Several services thus need to be combined to provide the functionality to fulfil the requested goals. This created value-added service is called composite service and its development process is called service composition (Dustdar and Schreiner, 2005). A composite service aggregates the functionalities of all its component services. The composite services in turn may involve in the composition process of other composite services. Assuming that composite services fulfil the requested requirements, service users have to go through a process to select the most suitable service to satisfy their desires. The process of making a service ready to be used is called service coordination and deployment. This process often comprises multiple deployment of interrelated software components into heterogeneous environments (Dastjerdi, 2013).

A growing number of services provide the same functionalities, and variant Quality of Service (QoS) makes the coordination and deployment process difficult and complicated. This thesis introduces an architecture for service selection and composition and investigates methodologies and algorithms for each phase to outperform service coordination and deployment in SOC environments. The reminder of this chapter details the need for service selection and composition and discusses the research problems, objectives, scope, significance, and organization of this thesis.

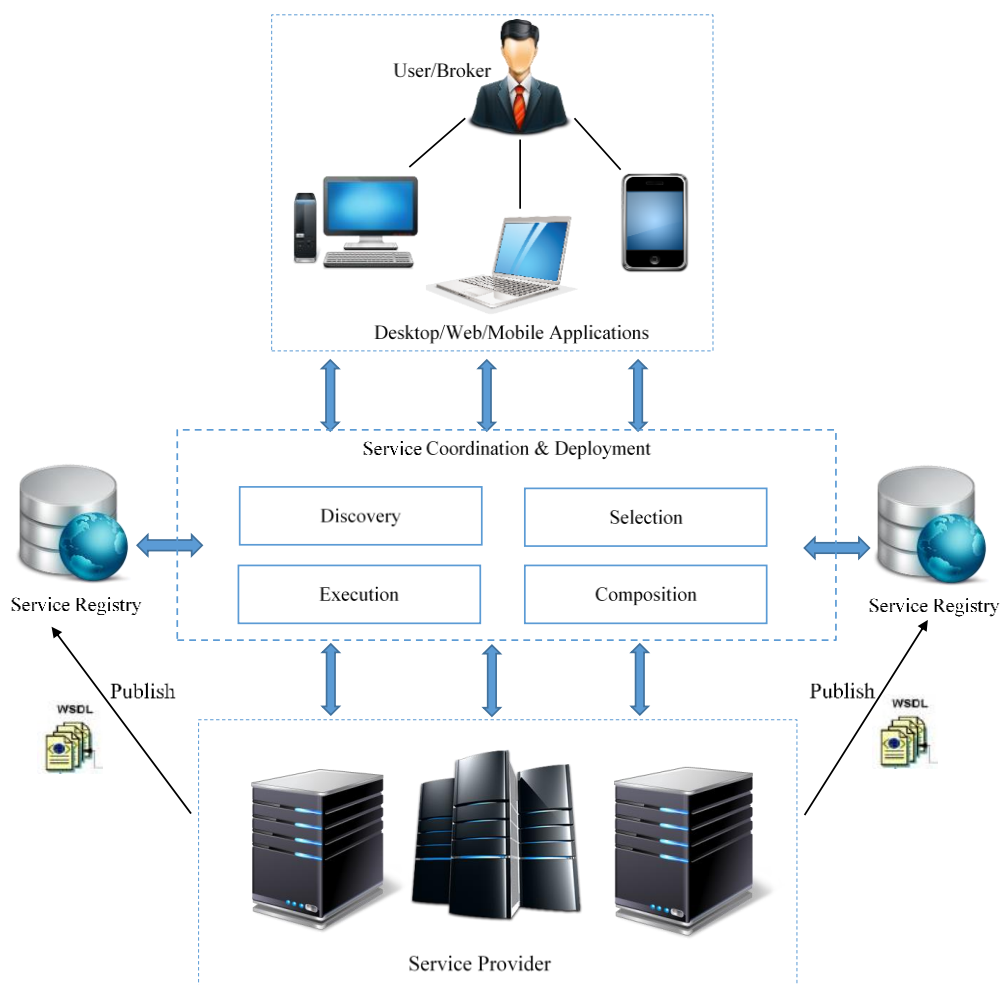
## **1.2 Background of the Problem**

The SOC has experienced the growth of X-as-a-service phenomenon leading to a profound evolution on system integration in B2C and B2B applications. Services aim to unify a variety of distinct disciplines such as business process management,

autonomic computing, distributed systems, knowledge-based systems, and networking, to name but a few (Bouguettaya *et al.*, 2014a). Service coordination and deployment plays a central role to fully realize this promising phenomenon as shown in Figure 1.1. It consists of several phases namely discovery, selection, composition, and execution. In the discovery phase, the best suited services among various available services - offered by different service providers- are discovered with respect to requested functionalities in user requirements (used as input). The discovered services provide the same functionalities and variant QoS (i.e., non-functional properties). The selection phase is responsible to select the best candidate services complying user desires on QoS criteria. Then, a composite service as a value-added service is created and executed based on the selected component services in the composition and execution phases, respectively.

Each of these phases have their own challenges and issues. The focus of this study is on service selection and composition phases. Selection phase faces a great number of discovered services claim same functionalities. It makes the selection decision difficult and complicated. QoS metrics are introduced to address this issue. The QoS of a service presents the non-functional properties in different aspects. The literature features varying QoS understandings. A QoS model of a service is defined in ISO 840216 and ITUE.80017 (Liu *et al.*, 2012). The service user's requirements can be properly reflected in this model. The QoS model can affect the service user's satisfaction from different aspects, such as the response time, success rate, reliability, availability, performance, and cost.

Selecting the best candidate service from numerous discovered services given different QoS values is considered a well-known research problems in the service computing area (Barakat *et al.*, 2014; Michlmayr *et al.*, 2010). A number of studies have been proposed to address this problem (Benouaret *et al.*, 2012a, 2012b; D'Mello and Ananthanarayana, 2010; Rehman *et al.*, 2014; Sun *et al.*, 2011). However, the QoS perceived by users does not always match the one promised by the service provider (Ishikawa, 2014; Pan and Baik, 2010). It leads to propose QoS evaluation of the Web services and provide feedbacks by third parties either service consumers or service evaluators (Tao *et al.*, 2012).



**Figure 1.1** High-level Architectural View of Service Computing Systems

However, none of the aforementioned approaches considered the evaluation of human agents, i.e., experts, in the service evaluation process. The limitation of the current evaluation solutions is that they can only evaluate the QoS attributes of a service by relying on monitoring services assessments. However, some services must be assessed based on user friendliness. Compared to experts, monitoring services are not suitable to evaluate such QoS criteria.

Different evaluator entities either human agents (e.g., experts) or software agents (e.g., monitoring services) are involved in the assessment of QoS parameters of candidate services in the other approaches (Hang and Singh, 2011; Hien Trang *et al.*, 2010; Mehdi *et al.*, 2012; Motallebi *et al.*, 2012; Paradesi *et al.*, 2009). They independently assess the promised QoS metrics of service based on the perceived facts. These facts are based on either their own experiences, i.e., first-hand information, or

other entities' experiences, i.e., second- or third-hand information. However, these assessments suffer from subjective or dishonest contributions and the trustworthiness levels of contributors are not considered. Moreover, the diversity of subjective evaluations imposes an obstacle to assess the service. The existing diversity necessitates a methodology to converge these evaluations to reach an agreement. Proposing an appropriate mechanism for QoS-aware assessment is considered the first research gap of this study.

Recently, Collaborative Decision Support Systems (CDSS) and techniques such as crowdsourcing and consensus present some potential solutions to address the convergence problem in SOC. Nonetheless, two important principles should be considered: first because services behave dynamically, past and current assessment should be differentiated to reach a consensus on service evaluation. Second because the trustworthiness of each crowd member evolves over time, a model to update and maintain this trust should be in place. This model works based on cooperative knowledge sharing between crowd members.

Furthermore, service users usually have different preferences with respect to QoS parameters and want to make trade-off between them. They would like these preferences and priorities to be considered in the QoS-aware selection process. Therefore, they need a system to support multi-criteria assessment and ranking and capture their preferences which incur complexity in selecting the best-suited candidate services. The proposed system should be able to specify and enforce user preferences while makes a multi-criteria selection decision. Addressing these complexities to support multi-criteria service selection with respect to the vague preferences of users (on multiple QoS criteria) is the second research gap that needs to be answered.

Cost of service is the subset of QoS that has been neglected in the majority of proposed existing approaches for service composition. In contrast, it is extensively investigated in the form of Service Level Agreement (SLA) in new emerging computing paradigms such as cloud and utility computing (Linlin and Rajkumar, 2012). SLA refers to “an explicit statement of exceptions and obligations that exist in a business relationship between two organizations: the service provider and customer” (Verma, 2004). Service providers specify the cost of offered service in the created

Service Level Agreement (SLA) templates. Service consumers then use the templates for negotiation on the cost of services. If both sides can reach an agreement, an SLA contract will be achieved.

Similar to the commodity-market, higher-reputed service providers offer higher service costs compared to the less-known ones. Service consumers tend to use more reliable services based on their affordability levels. As a result, a negotiation process should be in place to support trade-off between providers' supplies and users' demands. The negotiation failure (i.e. reach no agreement within negotiation deadline) for even a single atomic service leads to failure of the entire composition. Surplus management is the proposed solution to address this issue. (Richter *et al.*, 2012). However, unbalanced surplus distribution may lead to decrease the quality of composition. Proposing a suitable negotiation strategy to support budget-constrained service composition is a demanding task that is considered as the third research gap of this study.

Moreover, current SOC environments are becoming more open, changing, and dynamic. It makes adaptable and autonomous service composition a challenging task. Self-optimizing is one of the adaptable and autonomous composition aspects that needs to be resolved (Sheng *et al.*, 2014b). It concentrates on fulfilling QoS constraints in the selection of component services and achieving the self-optimized composite service. Proposing the appropriate mechanism to ensure achieving the self-optimized composite service and increasing the utility of entire composition introduces a significant research challenge to be addressed.

### **1.3 Statement of the Problem**

Nowadays, service computing is increasingly gaining momentum as latest emerging paradigm for distributed computing in order to change the way of design, delivery and consumption of software applications. In order to enhance and optimize the service deployment and coordination, it is important to exploit the benefits of autonomous, reliable, and optimized service selection and composition. The budget-constrained QoS-aware composition problem maps to multi-objective optimization



problem that is classified as NP-hard problem. It consists of selecting the best candidate services that maximizes QoS metrics and adhere to the budget constraints of users. It has attracted a great deal of interest in the context of SOC (Barakat *et al.*, 2014; Menascé *et al.*, 2010; Rehman *et al.*, 2014; Wang, 2009; Wu *et al.*, 2013). However, none of the existing approaches addressed this problem in an integrated manner, which is the focus of this research. The general research question this research plans to address is:

***“How an autonomous, reliable, and optimized service selection and composition would be achieved by integrating a novel crowdsourced consensus-aware service assessment, fuzzy service ranking, and budget-constrained service composition, respectively?”***

On a journey towards autonomous, reliable, and optimized service selection and composition, following questions will arise in each phase that need to be addressed:

**RQ1:** How to select the best candidate services reliably with respect to users’ QoS constraints and preferences utilizing the crowdsourced consensus-based methodology? (Service selection phase)

The proposed solution should be able to answer the following sub-questions raised in service assessment and ranking:

- i. How to employ the power of crowdsourcing, as a collaborative decision support system, to assess the QoS attributes of candidate services to not suffer from subjective or dishonest contributions?
- ii. How to converge diverse subjective QoS evaluations and reach consensus on the assessed candidate services considering dynamic behaviour of services and trustworthiness levels of crowd members?

- iii. How to capture and enforce user preferences in QoS-aware service ranking mechanism while reduce its complexity for non-expert users?
- iv. How to propose multi-criteria ranking mechanism for the assessed candidate services with respect to different QoS constraints and preferences of users?

**RQ2:** How to compose the best candidate services to support Pareto-optimal selection for each component service and increase the utility of entire composition autonomously? (Service composition phase)

The proposed solution should be able to answer the following sub-questions raised in service negotiation:

- i. What is the best SLA-based negotiation strategy for service composition?
- ii. How to utilize the power of surplus management to raise the chance of achieving an overall agreement in composition process (i.e. no negotiation failure for component services)?
- iii. How to achieve optimized surplus redistribution over the composite service to maximize QoS metrics and adhere to the budget constraints of users?

#### **1.4 Purpose of the Research**

The purpose of this research is to design an autonomous, reliable, and optimized service selection and composition to be used in service deployment and coordination for SOC environments by introducing a crowdsourced consensus-based service selection under fuzzy preferences of users and QoS-aware budget-constrained service composition using concurrent SLA negotiation and surplus management.

## 1.5 Objectives of the Research

Driven by the aforementioned challenges and research questions in the background and statement of the problem sections, the objectives of the research are identified as follows:

- i. To investigate the application of collaborative decision support systems and techniques in SOC and utilize their power to support service selection and composition
- ii. To eliminate the imposed diversity in QoS-aware assessment of service behaviour using the power of crowdsourcing and consensus theory to support reliable service selection
- iii. To develop multi-criteria service selection based on the consensus-achieved assessed QoS criteria and vague preference of users using fuzzy inference engine
- iv. To develop the autonomous optimized budget-constrained QoS-aware service composition using concurrent SLA-based negotiation and optimized surplus redistribution

## 1.6 Scope of the Research

Considering the aforementioned sections, this research was inspired by four research directions comprising collaborative decision support systems, Web service selection and composition, fuzzy inference systems, and SLA-based service negotiation. In this research:

- Crowdsourcing as collaborative decision support technique is utilized to support QoS-aware assessment of Web services

- Consensus as collaborative decision support technique is employed to converge diverse subjective assessments based on the trustworthiness levels of involved crowd members to support reliable service selection
- Fuzzy inference engine is used to support multi-criteria ranking strategy and handle and enforce vague preference of users on QoS metrics for service selection
- SLA-based concurrent negotiation is applied to support budget-constrained service composition
- Surplus redistribution is utilized to support self-optimized service composition

The discovery process of a crowd that supports QoS-aware service assessment and fulfills the required conditions is beyond the scope of this research. It is assumed that the suitable formed crowd is ready to be involved in the consensus process and this research only focuses on the consensus and aggregation processes.

## **1.7 Significance of the Research**

The advantages of service computing such as being platform-independent, loosely coupled, and standard-based encourage enterprises and companies to utilize it for low-cost and rapid developments of their distributed applications in heterogenous environments (Bouguettaya *et al.*, 2014b; Papazoglou and van den Heuvel, 2007; Yu *et al.*, 2008). SOC is continuously progressing to the extent that Internet of Services (IoS) will offer service consumers variant web services in all areas of their life and business in near future.

Considering a growing number of services provide the same functionalities and variant QoS, service users face a competitive situation to choose the accurate and appropriate services to fulfill their goals and desires. This leads to the problem of service selection and composition considered a NP-hard problem in SOC (Ben Mabrouk *et al.*, 2009b). Web service selection and composition is an active area of research in SOC that has been heavily investigated over the past decade (Ishikawa, 2014; Jula *et al.*, 2014; Sheng *et al.*, 2014b). Despite its massive improvements, the

process of selection and composition of Web Services is still considered as a complicated task due to the following reasons:

- First, dynamic behaviour of service results to QoS changes over the time. It necessitates the service assessment mechanism to be evolved over the time.
- Second, service assessment usually faces diversity of evaluations which may suffer from subjective or dishonest contributions.
- Third, service users have their own preferences on QoS metrics and budget constraints that need to be accounted in service selection and composition.
- Forth, service composition is required to select the best candidate services that maximizes QoS metrics while adheres to the budget constraints of users.

Moreover, rising the new emerging service oriented paradigms such as social computing, cloud computing, and Internet of things imposes new unaddressed challenges and requires revisit the previously addressed problems to propose new outperformed solutions. Considering the intrinsic nature of service computing, CDSSs have great potential to support service selection and composition. This research tries to open a new horizon for service selection and composition to utilize crowd-enabled consensus-based decision making.

## **1.8 Thesis Organization**

This chapter is completely explained the nature of the research, the facing problems, the purpose and objectives of the research to address these problems and scope of the research. The reminder of this thesis is organized as follows:

- Chapter 2 presents the background on research directions, discusses the unaddressed challenges, and describes literature review on existing works in service selection and composition

- The proposed research methodology is elaborated in Chapter 3 providing an overview of the research phases, analysis of requirements and explanations on development and evaluation of these phases.
- Chapter 4 presents research design and implementation introducing a crowd-enabled consensus-based service selection mechanism under fuzzy preference of users and Pareto-optimal service composition mechanism using SLA negotiation and surplus redistribution. The proposed techniques and algorithms are describes in details.
- Experimental results and discussion are provided in chapter 5 to indicate the applicability and feasibility of the proposed approaches and investigate their performance evaluations.
- Finally, the thesis is summarized and concluded in chapter 6 by discussing the contributions of this research and suggestions for future research directions.

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