PRIVACY-PRESERVED SECURITY-CONSCIOUS FRAMEWORK TO ENHANCE WEB SERVICE COMPOSITION

HOMA MOVAHEDNEJAD

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To my GOD, ***ALLAH***, who is always with me in every moment

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

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

To my dears ***mother***, ***father***, ***sisters***, and ***brothers***

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ABSTRACT

The emergence of loosely coupled and platform-independent Service-Oriented Computing (SOC) has encouraged the development of large computing infrastructures like the Internet, thus enabling organizations to share information and offer value-added services tailored to a wide range of user needs. Web Service Composition (WSC) has a pivotal role in realizing the vision of implementing just about any complex business processes. Although service composition assures cost-effective means of integrating applications over the Internet, it remains a significant challenge from various perspectives. Security and privacy are among the barriers preventing a more extensive application of WSC. First, users possess limited prior knowledge of security concepts. Second, WSC is hindered by having to identify the security required to protect critical user information. Therefore, the security available to users is usually not in accordance with their requirements. Moreover, the correlation between user input and orchestration architecture model is neglected in WSC with respect to selecting a high performance composition execution process. The proposed framework provides not only the opportunity to securely select services for use in the composition process but also handles service users' privacy requirements. All possible user input states are modelled with respect to the extracted user privacy preferences and security requirements. The proposed approach supports the mathematical modelling of centralized and decentralized orchestration regarding service provider privacy and security policies. The output is then utilized to compare and screen the candidate composition routes and to select the most secure composition route based on user requests. The D-optimal design is employed to select the best subset of all possible experiments and optimize the security conscious of privacy-preserving service composition. A Choreography Index Table (CIT) is constructed for selecting a suitable orchestration model for each user input and to recommend the selected model to the choreographed level. Results are promising that indicate the proposed framework can enhance the choreographed level of the Web service composition process in making adequate decisions to respond to user requests in terms of higher security and privacy. Moreover, the results reflect a significant value compared to conventional WSC, and WSC optimality was increased by an average of 50% using the proposed CIT.

ABSTRAK

Kemunculan ikatan pasangan yang longgar dan platform bebas Pengkomputeran Berorientasikan Perkhidmatan (SOC) telah menggalakkan pembangunan insfrastuktur komputeran yang besar seperti Internet, oleh itu ia membolehkan organisasi untuk berkongsi maklumat dan menawarkan perkhidmatan nilai tambah sesuai dengan keperluan pengguna yang luas. Komposisi Khidmat Laman Sesawang (WSC) memainkan peranan utama dalam merealisasikan wawasan untuk melaksanakan hampir semua proses perniagaan yang kompleks. Walaupun komposisi perkhidmatan menjamin cara yang kos efektif untuk mengintegrasikan aplikasi terhadap Internet, ia kekal sebagai satu cabaran penting dari pelbagai perspektif. Keselamatan dan rahsia adalah antara masalah yang menghalang lebih banyak aplikasi WSC. Pertama, pengguna memiliki pengetahuan awal yang terbatas mengenai konsep keselamatan. Kedua, penggunaan WSC tergendala disebabkan terpaksa mengenal pasti keselamatan yang diperlukan untuk mengawal maklumat pengguna yang kritikal. Oleh itu, keselamatan yang sedia ada pada pengguna biasanya tidak selari dengan keperluan mereka. Malah, hubung kait antara input pengguna dan model senibina orkestra diabaikan dalam penggunaan WSC bagi memilih proses pelaksanaan komposisi yang berprestasi tinggi. Rangka kerja yang dicadangkan bukan sahaja memberi peluang untuk memilih perkhidmatan yang selamat dalam proses komposisi tetapi juga mengendalikan keperluan kerahsiaan khidmat pengguna. Segala kemungkinan keadaan input pengguna dimodelkan dari segi keutamaan kerahsiaan pengguna dan keperluan keselamatan. Pendekatan yang dicadangkan menyokong pemodelan matematik terhadap orkestra berpusat dan tidak berpusat yang berkaitan dengan kerahsiaan khidmat pengguna dan polisi keselamatan. Hasil kerja kemudian digunakan untuk membanding dan menapis laluan komposisi calon dan memilih laluan komposisi yang terselamat berdasarkan permintaan pengguna. Reka bentuk optimum-D digunakan untuk memilih subset yang terbaik terhadap semua kemungkinan eksperimen dan meningkatkan kesedaran keselamatan terhadap komposisi perkidmatan kekal rahsia. Jadual Indek Koreografi (CIT) dirangka bagi memilih model koreografi yang sesuai untuk setiap input pengguna dan mencadangkan model yang dipilih kepada aras koreografi. Hasilnya menunjukkan rangka kerja yang dicadang boleh meningkatkan aras koreografi terhadap proses komposisi khidmat sesawang dalam membuat keputusan yang sesuai dengan permintaan pengguna dari segi keselamatan dan rahsia yang mantap. Juga, keputusan menggambarkan nilai yang signifikan apabila dibandingkan dengan WSC konvensional, dan keoptimuman WSC didapati bertambah sebanyak 50% dengan menggunakan CIT yang dicadangkan.

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g	-	Goal
rdi	-	Required data item
$\mathcal{S}$	-	Security
C	-	Confidentiality
I	-	Integrity
$\mathcal{A}$	-	Availability
$\mathcal{P}$	-	Provider
r	-	Role
dl	-	Delegation
$\mathcal{P}_O$	-	Orchestrator
p	-	Purpose
adi	-	Available data items
a	-	Action
v	-	Visibility
se	-	Sensitivity
ri	-	Risk
$\mathcal{UP}$	-	User privacy preference
se_H	-	Highest value of sensitivity
C_L	-	Confidentiality at low level
C_M	-	Confidentiality at medium level
C_H	-	Confidentiality at high level
ri_H	-	Highest value of risk
$\mathrm{I_L}$	-	Integrity at low level

$\mathrm{I_M}$	-	Integrity at medium level
$\mathrm{I_H}$	-	Integrity at high level
l	-	Depth level
$M_{Orch-Ce}$	-	Centralized orchestration model
$M_{Orch-De}$	-	Decentralized orchestration model
n_{CL}	-	Number of confidentiality at low level
n_{CM}	-	Number of confidentiality at medium level
n_{CH}	-	Number of confidentiality at high level
w_{CL}	-	Weight of confidentiality at low level
w_{CM}	-	Weight of confidentiality at medium level
w_{CH}	-	Weight of confidentiality at high level
n_{IL}	-	Number of integrity at low level
n_{IM}	-	Number of integrity at medium level
n_{IH}	-	Number of integrity at high level
w_{IL}	-	Weight of integrity at low level
w_{IM}	-	Weight of integrity at medium level
w_{IH}	-	Weight of integrity at high level
UI	-	User input
PP	-	Privacy policy of provider
ARQ_i	-	Available route quality for composition route i
N_D	-	Number of delegation
N_{Rp}	-	Number of requested purposes by service user
N_{Op}	-	Number of offered purposes in composition route
N_p	-	Number of providers involved in composition route
C_R	-	Confidentiality level required based on user preferences
C_P	-	Confidentiality level provided by composition route
I_R	-	Integrity level required based on user preferences
I_P	-	Integrity level provided by composition route
N_R	-	Number of routes
CS	-	Component web service

LIST OF ABBREVIATIONS

ABAC	-	Attribute-Based Access Control Model
ACL	-	Access Control List
AHP	-	Analytical Hierarchy Process
ANOVA	-	Analysis of Variance
Anti-DoS	-	Anti-Denial of Service
BBD	-	Box-Behnken Designs
BPMN	-	Business Process Modeling Notation
B2C	-	Business-to-Consumer
CCD	-	Central Composite Design
CIA	-	Confidentiality, Integrity, and Availability
CIT	-	Choreography Index Table
DaaS	-	Data-as-a-Service
DAC	-	Discretionary Access Control Model
DM	-	Dominance Method
DOE	-	Design of Experiments
IBAC	-	Identity Based Access Control Model
IDS	-	Intrusion Detection System
IPS	-	Intrusion Prevention System
IoT	-	Internet of Things
MAC	-	Mandatory Access Control Model
MADM	-	Multi Attribute Decision Making
MCDM	-	Multi Criteria Decision Making

MODM	-	Multi Objective Decision Making
NIST	-	National Institute of Standards and Technology
PBAC	-	Policy-Based Access Control Model
PN	-	Private Negotiator
QoS	-	Quality of Service
RAdAC	-	Risk Adaptive Access Control Model
RBAC	-	Role-based Access Control Model
RE	-	Requirement Engineering
RFID	-	Radio-Frequency Identification
RSM	-	Response Surface Methodology
RTD	-	Round Trip Delay
SAW	-	Simple Additive weighting
SI*	-	Secure i*
SOA	-	Service Oriented Architecture
SOC	-	Service Oriented Computing
SOAP	-	Simple Object Access Protocol
TBAC	-	Task Based Access Control Model
UDDI	-	Universal Description, Discovery, and Integration
URI	-	Universal Resource Identifier
URL	-	Universal Resource Locator
OWL-S	-	Web Ontology Language for Web Services
WS-BPEL	-	Web Services Business Process Execution Language
WSC	-	Web Service Composition
WS-CDL		Web Service Choreography Description Language
WSDL	-	Web Service Description Language
WS-Federation	-	Web Service Federation
WSML	-	Web Service Modeling Language

WSMO	-	Web Service Modeling Ontology
WSMS	-	Web Service Management System
WS-Security	-	Web Service Security
WS-Trust	-	Web Service Trust
XML	-	eXtensible Markup Language

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CHAPTER 1

INTRODUCTION

1.1 Overview

Service-Oriented Computing (SOC) has adapted new ways of software application design, delivery, and use over the last decade. SOC relies on services as fundamental elements that promise the development of rapid and low-cost distributed applications in heterogeneous environments (Yu *et al.*, 2008). The goal of SOC is to achieve platform-independent, standard-based and loosely coupled distributed computing. To realize this aim, an architectural model is established with Service-Oriented Architecture (SOA) that organizes software infrastructures and applications into a set of interacting services. These services can be published, discovered, and used by other services. The most promising choice in accomplishing SOA objectives is Web service technology (Papazoglou and van den Heuvel, 2007). Sheng *et al.* (2014b) defined a Web service as "a semantically well-defined abstraction of a set of computational or physical activities involving a number of resources, intended to fulfil a customer need or a business requirement". Standard-based languages and Internet-based protocols have been utilized to describe, advertise, and discover Web services.

A sizable body of literature has investigated service composition as a key challenge of SOC and SOA (Bouguettaya *et al.*, 2014g). The basic blocks of service computing are atomic services whose interoperations realize distributed applications. SOC cannot achieve its full potential unless the service composition challenge is appropriately addressed to provide more powerful value-added services and applications. Service composition enables organizations and enterprises to outsource functionalities, form alliances, and deliver professional services to their customers. It leads to reduce their cost and risk in building new business applications (Sheng *et al.*, 2014b).

Although service composition promises cost-effective means of integrating applications over the Internet, it remains an important challenge from a the non-functional perspective known as Quality of Service (QoS) (Halvard, 2009). Different aspects of non-functional properties of a service are presented in its QoS. The literature features various QoS considerations. According to Liu *et al.* (2012), ISO 840216 and ITUE.80017 are utilized to model QoS metrics of a service. They may include but are not limited to success rate, response time, availability, reliability, cost, privacy, trustworthiness, and security. Among these QoS metrics, security and privacy are of great importance to adopting service composition considering the fact that SOC environments are becoming more dynamic and open (Bouguettaya *et al.*, 2014a; Noor *et al.*, 2013; Satoh and Tokuda, 2011).

Secure service computing is increasingly gaining momentum in ensuring that users' private data are securely processed and handled. A Number of Web service standards have been proposed by industry and academia including WS-Security (OASIS, 2006), WS-Federation (OASIS, 2009), and WS-Trust (OASIS, 2007b). Nonetheless, they have not fully paved the way to secure service composition yet, the reason being that they were originally proposed for atomic services and cannot address the challenges related to composite services (Sheng *et al.*, 2014b). A few works have mainly concentrated on secure service composition (Brucker *et al.*, 2013; Dragovic *et al.*, 2014; Karatas *et al.*, 2015). However, privacy concerns are neglected in existing works (Costante *et al.*, 2013c). Therefore, the current research investigates the problem of secure service composition and introduces an integrated approach to address this challenge from two key perspectives: security and privacy. This study not only provides an opportunity to securely select services for use in the composition process but also to handle service users' privacy requirements.

The remainder of this chapter explains the need for secure and private service composition. The research problem, objectives, and scope are also discussed, respectively. The significance of the research and the thesis organization are presented in the final section of this chapter.

1.2 Background of the Problem

Service-Oriented Computing (SOC) is facing the growth of the everything-as-a-service (or X-as-a-service) phenomenon, resulting in the significant evolution of system integration in Business-to-Consumer (B2C) and Business-to-Business (B2B) applications. Web service coordination and deployment as a process of making a service ready to be used is crucial to fully realizing this promising phenomenon (Dastjerdi, 2013). It comprises several steps including discovery, selection, composition, and execution.

Web service discovery is responsible for publishing service descriptions and details in Universal Description, Discovery, and Integration (UDDI) repositories so those services are discoverable by potential consumers. Service discovery may return several web services that provide the same functionality (da Silva *et al.*, 2011). Therefore, selecting the best candidate services among numerous functionally-equal services discovered is a primary mission of Web service selection. To achieve this goal, service selection involves non-functional properties of Web services known as Quality of Service (QoS) metrics (Moghaddam and Davis, 2014; Raj and Sasipraba, 2010). However, component services cannot generally satisfy user demands. A process is necessary to combine existing services to fulfil the requested goals. Hence, a value-added service, namely composite service, is created in the Web service composition step using selected component services (Carminati *et al.*, 2015). The composite service created is finally implemented to address user requirements in the Web service execution step.

As Web services are progressively adopted for Internet-based applications, QoS-aware service selection and composition has become a well-known research problem in the service computing area (Barakat *et al.*, 2014; Zheng *et al.*, 2011). A wealth of literature has addressed this problem (D'Mello and Ananthanarayana, 2010; Strunk, 2010; Sun *et al.*, 2011). Different aspects of the QoS-aware service selection and composition challenge have been investigated and referred in existing approaches (El Hadad *et al.*, 2010; Ngu *et al.*, 2010; Zheng *et al.*, 2013). However, privacy and security as two imperative aspects of QoS have attracted less attention. Critical private and business data and information are transferred in service workflows either directly or indirectly. This fact highlights the importance of security in SOC (Karatas *et al.*, 2015). Moreover, sensitive information exchanges between parties involved in the process of service composition raises the issue of service users' information privacy (Carminati *et al.*, 2015; Sun *et al.*, 2014).

The problem of security and privacy is a well-known research problem in the service computing field (Bouguettaya *et al.*, 2014a; Carminati *et al.*, 2015; Satoh and Tokuda, 2011). A number of research and standardization efforts have been proposed to deal with these matters. WS-Federation (OASIS, 2009), WS-Security(OASIS, 2006), and WS-Trust (OASIS, 2012) are instances of such efforts. However, the applicability and feasibility of these standards have not been fully proven for service composition, as they were originally devised for single component services (Sheng *et al.*, 2014b). In fact, the majority of early works have focused on handling security and privacy issues for single atomic services. With the increasing importance of service composition, a considerable number of research works are investigating the problem of security and privacy for composite services in recent years. Different security matters, including integrity, confidentiality, and accountability i.e., authentication and authorization are highlighted in several research works (Alrifai *et al.*, 2012; Immonen and Pakkala, 2014; Tabatabaei *et al.*, 2010). Trustworthy and privacy-preserving service composition is also investigated in existing research (Costante *et al.*, 2013c; Dalpiaz *et al.*, 2014; Tbahriti *et al.*, 2011; Tbahriti *et al.*, 2013; Zhang *et al.*, 2014).

Although only security or privacy is necessary, but they are insufficient to accomplish secure private service composition. Fulfilling security requirements does not guarantee that all privacy dimensions of user information will be covered and vice versa. Some literature considers privacy as a sub-class of security (W3C, 2003a, 2004c), while a number of studies deem security a sub-class of privacy (Carminati *et al.*, 2015; Squicciarini *et al.*, 2013). Nevertheless, security and privacy are interrelated, as defined by OASIS (2010), and need to be considered together to protect sensitive information. An appropriate mechanism to support security-aware and privacy-enabled service composition should be proposed. Different elements are involved in providing a new value-added composite service for solving the more complex problems with respect to the security and privacy constraints required (Sheng *et al.*, 2014b). All these elements play an important role in accomplishing the task and affect the composition process in specific ways. To investigate the effect of each element on the service composition process, statistical analysis is normally utilized. It is necessary to propose mathematical modeling of each element to conduct a statistical analysis on the service composition process. Statistical analysis necessitates the proposed mathematical models to examine the effectiveness of each element with respect to the security-aware privacy-enabled service composition. Proposing an appropriate modeling mechanism to handle this matter is considered the first research gap identified in this study.

From a service users' point of view, protecting their in-transit sensitive data is of paramount importance in unpredictable and open SOC environments. Users often express concerns via declared privacy preferences. At the same time, the privacy policies of service providers must comply with the expressed user privacy preferences. Moreover, service providers' privacy policies are grounded on security concepts while service users declare their preferences based on the privacy dimensions. As a result, two heterogeneous concepts render the compliance process more complicated. In addition, the intrinsic complexity of security concepts poses many difficulties for service users who have limited knowledge of security requirements. Such complexities necessitate a methodology to bridge security requirements based on the modeled privacy preferences expressed. Thus, bridging the gap can help non-expert users protect critical information while not compelling them to have prior knowledge of security concepts. It can also facilitate the compliance process between required service user preferences and existing service provider policies. It is expected this bridge will eliminate the subject of heterogeneity in the compliance process. Addressing this issue is the second research gap that needs to be filled in this study.

Furthermore, service composition is often modeled in either centralized or decentralized orchestration. Centralized orchestrated service composition is grounded on centralized architecture, whereby the central entity coordinates interactions between the entities involved in accomplishing the required task. On the other hand, decentralized orchestrated service composition is based on the distributed architecture, where the entities involved collaborate toward achieving a predefined goal without the presence of a centralized coordinator. The choreographed composite services may choose either of these composition modeling types with respect to their specific advantages and privileges. Some research works (Chafle *et al.*, 2004; Ghosal and Mann, 2012) offer the decentralized orchestration model as a model with improved performance in terms of lower response time and higher scalability and throughput. Other researchers (Schonberger and Wirtz, 2012) believe that centralized orchestration guarantees higher levels of security as sensitive information is exposed to fewer entities.

The current literature suffers from overlooking two matters. First, they only investigate whether the proposed composition model fulfils the security requirements with respect to direct user requests. They do not consider selecting a model that provides the higher possible security level(s). Second, making a trade-off between performance and security in choosing a suitable composition execution process is a demanding task that is ignored in existing approaches. Therefore, it is important to select a high performance composition execution process while maintaining the higher possible security level(s). Addressing the abovementioned concerns is considered as filling the third research gap in this study.

1.3 Statement of the Problem

Distributed computing has witnessed a new generation of platforms with the help of SOC concepts in heterogeneous environments, wherein interoperable services facilitate low-cost and rapid development of distributed applications (Moghaddam and Davis, 2014). WSC, as one of the core concepts of SOC, has been widely utilized, enabling existing services to create new value-added services and share autonomously and independently (El Hadad *et al.*, 2010; Wu *et al.*, 2014). Due to the significance of WSC, it has been heavily investigated in both academia and industries. Despite the progressive improvement, a number of issues have not been appropriately addressed (Bouguettaya *et al.*, 2014a; Sheng *et al.*, 2014b).

Security and privacy are among the problematic barriers that prevent the wider application of WSC and still need to be investigated. They have attracted a great deal of interest in the WSC context. A wealth of literature has explored the secure service composition problem (Brucker *et al.*, 2013; Carminati *et al.*, 2014; Karatas *et al.*, 2015;

Pino and Spanoudakis, 2012; Satoh and Tokuda, 2011). Several research efforts have also been devoted to addressing privacy in service composition (Carminati *et al.*, 2015; Costante *et al.*, 2013a; Jensen, 2013; Squicciarini *et al.*, 2013; Tbahriti *et al.*, 2014). As discussed in the previous section, security and privacy are interrelated, but no existing research works address the problem of security and privacy-based service composition in an interactive manner, which is the focus of this research. The general research question to be answered through this research is:

"How can a security-conscious privacy-preserving service composition be achieved by linking users' security requirements with their privacy preferences; integrating modeling of users' privacy preferences, service providers' privacy policies, and the composition execution process; and selecting the most secure possible composition route(s)?"

On a journey towards security-conscious privacy-preserving service composition, the following questions arising in each phase need to be addressed:

RQ1: How can user input that preserves privacy preference be appropriately modeled? (User input modeling phase)

The proposed solution should be able to answer the following sub-questions raised regarding user input modeling process:

i. How are security requirements inferred based on the privacy preferences expressed by users without their interventions?

ii. How can all possible user input states be mathematically modeled with respect to the defined privacy dimensions?

RQ2: How can the composition execution process be properly modeled to preserve the privacy policies of service providers? (Web service composition modeling phase)

The proposed solution should be able to answer the following sub-question raised regarding modeling of the Web service composition execution process:

i. How can centralized and decentralized orchestration execution be mathematically modeled with respect to all possible states of service providers' privacy policies?

RQ3: How can the most secure possible composition route(s) be selected to preserve both privacy preferences and privacy policies of service users and providers, respectively? (Selection and optimization phase)

The proposed solution should be able to answer the following sub-questions raised regarding the service comparison and selection process:

i. How can the modeled user input be matched against the modeled composition execution processes (i.e., centralized and decentralized orchestration) based on the defined security requirements and privacy preferences?

ii. How can a multi-criteria selection mechanism be proposed for the matched candidate services to screen and then select composition route(s) with the highest possible security?

iii. How can the power of the empirical optimization technique be employed in selecting a high-performance composition model (i.e., centralized or decentralized orchestration) based on user requests while maintaining the highest possible security level(s)?

1.4 Purpose of the Research

The purpose of this research is to design a security-conscious and privacy-preserving service composition for use in service deployment and coordination for SOC environments. Mathematical modeling of service user privacy preferences in the form of user input, mathematical modeling of service providers' privacy policies in the form of centralized and decentralized orchestration is introduced, and an empirical optimization technique is presented.

1.5 Objectives of the Research

The main objective of this study is to model all states of user input and the Web service composition process and then introduce an approach to identify the desired route(s) in an appropriate execution model (centralized or decentralized orchestration) in terms of security requirements and privacy preferences. Therefore, the sub objectives of this research are outlined as follows:

1. To identify the required security based on user privacy preference.

2. To develop a mathematical model for user input that can fulfil all states of privacy preference.

3. To develop mathematical models for centralized and decentralized orchestrations that include all states of service providers' privacy policy.

4. To develop a mathematical model to compare the developed user input state with the developed centralized and decentralized orchestration states in terms of the required security and privacy identified.

5. To employ a multi-criteria decision-making method on the outcome of comparison model to find the composition route(s) with the highest possible security.

6. To develop empirical models that represents the relationship between independent variables (including purposes, available data items, action types and roles) and dependent variables (including Available Route

Number (ARN) and Available Route Quality (ARQ)) for centralized and decentralized orchestrations to be used for optimization.

1.6 Scope of the Research

This research was inspired by four research directions, namely service selection and composition, security and privacy, multi-criteria decision-making, and statistical-based optimization. In this research:

1. The Web service composition process is limited to the two, choreographed and execution process levels.
2. The information that users can provide as user input are purpose, available data items, visibility, and actions (read-only, modify).
3. The security of the Web service composition process is limited to the CIA principles i.e., confidentiality, integrity, and availability in the orchestration model.
4. The features designed for providers are based on the user inputs and include the goal, requested data items, role, and defined security.
5. The privacy extracted from user input is restricted to the sensitivity and risk concepts, which are directly related to the availability of data items and their actions.
6. The user input states and modeled composition routes of orchestrations (centralized and decentralized) are compared against user request, extracted privacy and defined security criteria.
7. The empirical models are designed based on the D-Optimal method and are employed to optimize the dependent variables (purposes, available data items, action types and roles) and independent variables (including ARN and ARQ).

The choreographed level in this study is assumed to illustrate the service composition architecture and to demonstrate the empirical model's outcome to select the best composition execution process. Investigating choreographed level details is beyond the scope of this research.

1.7 Significance of the Research

The emergence of loosely coupled and platform-independent SOC eventuates building large computing infrastructures like the Internet, which enable organizations to share information and offer value-added services tailored to all variant needs of users. Web service composition plays a key role in realizing this vision of implementing almost any complex business process (Carminati *et al.*, 2014; Costante *et al.*, 2013c; Karatas *et al.*, 2015).

A growing number of services provide the same functionalities and variant QoS, resulting in a sizable body of literature on QoS-aware service composition. Despite the massive improvements, service composition suffers from improperly addressed challenges. Privacy and security are the two most important challenges that have attracted less attention owing to their complexity. Therefore, security and privacy-aware service composition is still considered a complicated task

Moreover, the increase in newly emerging SOC paradigms such as cloud computing, and Internet of Things imposes new, unaddressed privacy and security challenges, requiring revisiting the previously addressed problems to propose new outperforming solutions. This research endeavours to open a new horizon for security-conscious privacy-preserving service composition to more securely and privately serve user requests.

1.8 Thesis Organization

This chapter fully discussed the nature of the research, the research gaps and problems faced, the research purpose and objectives, how these research gaps and problems will be addressed, as well as the research scope and significance. The remainder of this thesis is organized as follows:

The second chapter describes a background on research directions, explains the unaddressed challenges, and presents a literature review of existing works on service selection and composition. The proposed research methodology is discussed in

Chapter 3 by providing an overview of the research phases, operational framework, and explanations on the validation and evaluation of these phases.

The forth chapter presents the research design and implementation by introducing the mathematical modeling of the security-conscious privacy-preserving Web service composition process. The proposed techniques and algorithms are described in detail.

The experimental results and a discussion are provided in Chapter 5 to indicate the applicability and feasibility of the proposed approach and investigate its evaluation and validation. Finally, a summary and conclusions of the thesis are provided in Chapter 6 by discussing the contributions of this research and suggesting for potential future research directions.

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