



***A MULTI-LEVEL FRAMEWORK FOR EFFICIENT SENSITIVE DATA
TRANSMISSION IN CLOUD COMPUTING***

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TRANSMISSION IN CLOUD COMPUTING**

By

HAIFAA JASSIM MUHASIN

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

June 2019

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DEDICATION

This thesis is dedicated to my dear Father, to spirit of my dear Mother, to the spirit of my dear sister Huda, to my beloved Husband Malik, to my beloved Brothers and Sisters, to my wonderful Daughter Farkad and my beloved Son Sarmad and his beloved wife Eman for their endless love, support, and encouragement



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

A MULTI-LEVEL FRAMEWORK FOR EFFICIENT SENSITIVE DATA TRANSMISSION IN CLOUD COMPUTING

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June 2019

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Cloud computing, as a growing field, can provide the needs of enterprises and individuals to access cloud computing resources and meet their organizational computing requirements. The popularity of cloud computing is characterized by a number of great features, such as scalability, low cost and unlimited resources. These features have encouraged many organizations and individuals to transfer their data over the cloud. However, cloud computing is constrained by security and privacy issues, particularly by factors on confidentiality, integrity, availability and privacy, apart from access control, management and internal attacks. These issues have become a major challenge in using the cloud, especially when dealing with sensitive data.

The aim of this study is to address the problem of protection in terms of privacy and security of data from the perspective of management of information systems (MIS) and its decision-making process. Here, the factors related to the management and protection of sensitive data in cloud computing are data confidentiality (DC), data integrity (DI), data privacy (DP) and data availability (DA). The analyses of these factors are performed on the basis of the interests of managers and individuals whose aim is to protect sensitive data over the cloud.

The experimental study in this research includes a pilot study, the development of a tool as a proof of concept and an experts' interview. The tool, which is developed on the basis of the proposed framework, is verified by the interviewed experts and through tool execution. The results from the interviews confirm the validity and workability of the proposed framework in enhancing the decision making of MIS and managing and protecting sensitive data over the cloud. Subsequently, the

anonymization method of the proposed framework is compared with the encryption approach of previous work.

The research applies the anonymization technique and classifies the contents of a sensitive data file by the k-anonymity technique, which can efficiently protect sensitive data and reduce the transmission time and size of a file sent over the cloud. The digital signature of the file containing sensitive data is generated and sent together with the file to ensure DI. Private and confidential data management issues of intrusion and data loss over the cloud are solved by using the proposed multi-level framework, which applies the method of responsible participation to maintain DC and DA upon request—the other major contribution of this research.

This study has achieved its stated objectives. The results obtained by the experimental study are aligned with the proposed framework and the concept of protection and management of private confidential data for effective information management decision making.

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

**RANGKA KERJA BERBILANG ARAS BAGI PENGHANTARAN DATA
SENSITIF YANG CEKAP DALAM PENGKOMPUTERAN AWAN**

Oleh

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Pengkomputeran awan adalah bidang yang berkembang, mengemukakan keperluan enterpris dan individu untuk capaian sumber dalam komputeran awan bagi memenuhi keperluan pengkomputeran organisasi tersebut. Kepopularan komputeran awan adalah berdasarkan banyak ciri-ciri hebat seperti penskalaan, kos yang rendah dan sumber tanpa had. Ciri-ciri ini menggalakkan organisasi dan individu untuk memindah data mereka ke dalam awan. Justeru itu, keselamatan dan kerahsiaan menjadi isu utama dalam pengkomputeran awan yang melibatkan faktor-faktor kerahsiaan, keutuhan, kebolehsediaan dan kerahsiaan, juga kawalan capaian, pengurusan dan serangan dari dalam. Kerisauan ini menjadi cabaran terbesar dalam pengkomputeran awan, terutamanya apabila melibatkan data yang sensitif.

Matlamat kajian ini adalah untuk menumpukan perhatian terhadap permasalahan berkaitan perlindungan data peribadi dan keselamatannya dari perspektif pengurusan sistem maklumat dan pembuatan keputusan.

Faktor pengurusan dan perlindungan data sensitif dalam perkomputeran awan yang dikaji dalam kajian ini adalah kerahsiaan data (DC), keutuhan data (DI), privasi (DP) dan kebolehsediaan (DA). Analisa kepada keempat-empat faktor telah dilaksanakan berdasarkan keputusan profesional pengurus-pengurus ini. Kepentingan perkaitan.

Kajian eksperimen yang dilaksanakan dalam penyelidikan ini merangkumi kajian awal, pembangunan peralatan sebagai pembuktian konsep dan temubual pakar. Peralatan ini dibangunkan berasaskan rangka kerja yang dicadangkan dan peralatan

ini telah diverifikasi oleh pakar melalui sesi temubual dan pelaksanaan peralatan. Hasil dari temubual mengesahkan kesahihan dan kebolehlaksana rangka kerja yang dicadangkan bagi mempertingkatkan pengurusan pembuatan keputusan sistem maklumat data sensitif dalam persekitaran awan. Selanjutnya, kaedah *anonymization* rangka kerja yang dicadangkan dibandingkan dengan pendekatan penyulitan kerja sebelumnya.

Kajian ini mengaplikasi teknik *anonymization* dan pengelasan kandungan fail data sensitif menggunakan teknik *k-anonymity*, yang terbukti cekap untuk melindungi data sensitif, masa penghantaran lebih pantas dan saiz fail diubah yang lebih kecil yang akan dihantar ke awan. Tandatangan digital yang spesifik bagi fail yang mengandungi data sensitif tersebut akan dijana dan dihantar bersekali dengan fail bagi memastikan keutuhan data di pihak penerima. Isu pengurusan data peribadi dan sulit seperti penyamaran dan kehilangan data dalam awan dapat dicegah dengan menggunakan rangka kerja berbilang aras yang dicadangkan ini, yang mengaplikasi pendekatan penyertaan bertanggungjawab, bagi mengekalkan kerahsiaan dan kebolehcapaian fail berkeselamatan.

kajian ini telah mencapai objektif yang dinyatakan. Keputusan yang diperolehi melalui kajian eksperimental adalah selaras dengan objektif rangka kerja yang selaras dengan cabaran dalam perlindungan dan pengurusan data persendirian dan rahsia bagi pengurusan pembuatan keputusan maklumat yang lebih cekap.

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

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TABLE OF CONTENTS

	Page
ABSTRACT	i
ABSTRAK	iii
ACKNOWLEDGEMENTS	v
APPROVAL	vi
DECLARATION	viii
LIST OF TABLES	xiii
LIST OF FIGURES	xiv
LIST OF ABBREVIATIONS	xvi
CHAPTER	
1 INTRODUCTION	1
1.1 Overview	1
1.2 Research Problem	2
1.3 Research Questions	3
1.4 Research Objectives	4
1.5 Research Motivation	4
1.6 Research Contributions	4
1.7 Research Scope	4
1.8 Thesis Organization	5
2 LITERATURE REVIEW	6
2.1 Introduction	6
2.2 Cloud Computing Environment	6
2.3 Information Systems	8
2.4 Management Information Systems	10
2.5 Data Management	11
2.6 Decision Making	12
2.7 Sensitive Data	13
2.7.1 Data Anonymization	14
2.7.2 Digital Signature	15
2.8 Security and Privacy in Transmitted Data Management	16
2.8.1 Confidentiality in Data Management	16
2.8.2 Privacy in Data Management	18
2.8.3 Integrity and authorization in Data Management	19
2.8.4 Availability in Data Management	20
2.8.5 Authentication in Data Management	20
2.8.6 Anonymization in Data Management	20
2.9 Data Security and Privacy Requirements	21
2.10 Management Sensitive Data Models and Methods	23
2.11 Gap Analysis	25
2.12 Summary	31

3	RESEARCH METHODOLOGY	32
3.1	Introduction	32
3.2	Research Activity Design	32
3.2.1	Related Work Reviews	33
3.2.2	Framework Design	34
3.2.3	Pilot Study Design	34
3.2.4	Research Design	38
3.2.5	Implementation of MLF Tools	39
3.2.6	Validity and Data Analysis Design	39
3.3	Summary	39
4	NEW PROPOSED MULTI-LEVEL FRAMEWORK	40
4.1	Introduction	40
4.2	Sensitive Data Management Factors	40
4.2.1	Hypothesis Model	42
4.3	MLF Design	44
4.3.1	Part 1: User-Side Module Design	46
4.3.1.1	Data Anonymity	49
4.3.1.2	Digital Signature Creation	52
4.3.2	Part 2: Cloud-Side Module Design	57
4.3.2.1	User Authorization Module	63
4.3.2.2	Authentication Module	66
4.3.2.3	Save or Retrieve Data File	74
4.3.2.4	User Request	77
4.4	Summary	79
5	RESULTS AND DISCUSSION	80
5.1	Introduction	80
5.2	Results of Pilot Study	80
5.2.1	Structured Interview Results	80
5.2.2	Survey Results	85
5.3	Programming Language	92
5.4	User Side	93
5.4.1	Data Anonymity Function	93
5.4.2	Digital Signature Creation	94
5.5	Cloud Side	94
5.5.1	User Authorization	95
5.5.2	Authentication	96
5.5.3	Save or Retrieve Data File	97
5.6	Validation of the Current Research	97
5.6.1	Validation of the Proposed MLF	99
5.6.2	Validation of the Implementation Program	101
5.6.3	Validation of the Contributions of the Research	102
5.7	Comparison of results of our research and those of previous studies	103
5.8	Discussion	104
5.9	Summary	105

6	CONCLUSION AND FUTURE WORK	106
6.1	Introduction	106
6.2	Conclusion	106
6.3	Contribution of the Current Research	107
6.4	Future Research	107
	REFERENCES	109
	APPENDICES	119
	BIODATA OF STUDENT	184
	LIST OF PUBLICATIONS	185



LIST OF TABLES

Table		Page
2.1	Factors that influence the information system decision on sensitive data management	21
2.2	Gap analysis	26
2.3	Factors that affect sensitive data in cloud computing and their connection to related work	27
5.1	Results of the structured interviews	83
5.2	Frequency of responses from the nine experts, with percentages	84
5.3	Mapping the hypotheses of the MLF framework based on the instrument questions and the results of the reliability tests	87
5.4	Statistics of reliability coefficients 1	91
5.5	Statistics of reliability coefficients 2	92
5.6	Validation test from the experts' interview	98
5.7	Details of interview respondents for validation research	98
5.8	Comparison between anonymity and encryption of files in terms of time and size	104
5.9	Evaluation and validation objectives	105

LIST OF FIGURES

Figure	Page	
2.1	Distinct functions of information systems	10
2.2	Classification of attributes in anonymization technique	15
2.3	Factors the affect sensitive data management over the cloud	23
3.1	Research activities	33
3.2	Pilot experiment design and processes	35
4.1	The research model with the factors of decision making of information systems on sensitive data management	41
4.2	Proposed model hypothesis	42
4.3	Proposed MLF	43
4.4	The proposed framework explains all parts and modules	46
4.5	Flow of user-side modules	47
4.6	User-part module flowchart	48
4.7	Main screen of the user-part modules	49
4.8	File content before sending. (pre-anonymization)	50
4.9	File content after anonymiztion (post-anonymization)	50
4.10	Data anonymity module flow	51
4.11	Asymmetric encryption method of RSA to compute hash $H(M)$	54
4.12	Digital signature by DSA for sensitive data file flow	57
4.13	Management information system of sensitive data in cloud computing for the comprehensive flow of the MLF tool	60
4.14	Registration page	61
4.15	Login page	61
4.16	Sign-in login page	62
4.17	Main screen to manage sensitive data in cloud computing	62
4.18	User authorization flow	64

4.19	Manager directory attributes	66
4.20	Authentication flow	68
4.21	‘Entered encrypted code’ flow	69
4.22	‘Verify Digital Signature’ Flow	73
4.23	SAP directory and shared file directory attributes	74
4.24	‘Save or Retrieve Data File’ Flow	75
4.25	CSP directory attributes	76
4.26	User request flow	78
5.1	User-side interface screen	93
5.2	Cloud-side main interface screen	95

LIST OF ABBREVIATIONS

CSLs	Certificate Symbols Lists
CSP	Cloud Service Provider
DA	Data Availability
DAMA	Data Management Association
DC	Data Confidentiality
DI	Data Integrity
DP	Data Privacy
DSA	Digital Signature Algorithm
IaaS	Infrastructure-as-a-Service
IDEC	Information and communications Development Center
IS	Information System
ISMS	Information Security Management Systems
IT	Information Technology
LR	Literature Review
MCDB	Multi Cloud DataBase
MIS	Management Information Systems
MLF	Multi-level Framework
NIST	National Institute for Standards and Technology
NoAcM	Number of Access Control from Manager
NoAu	Number of Access User
NoAUs	Number of Authorized Users
NoDCs	Number of Data Centers
NoDTs	Number of Data Types
NoEncCs	Number of Encrypted Codes
NoRs	Number of Resources

NoSecPrM	Number of Security and Privacy Mechanism
PaaS	Platform-as-a-Service
PHR	Personal Health Record
PII	Personally Identifiable Information
SaaS	Software-as-a-Service
SAP	Security Auditor Party
SPSS	Statistical Package for the Social Science



CHAPTER 1

INTRODUCTION

1.1 Overview

Cloud computing offers three major types of service models: software-as-a-service (SaaS) model, platform-as-a-service (PaaS) model and infrastructure-as-a-service (IaaS) model. The information technology (IT) of a cloud computing infrastructure consists of networks based on IP software, services and virtual interfaces. The cloud uses different models of services, such as hybrid, community, private or public cloud models. Cloud computing has created a new understanding amongst companies and organizations in conducting information exchange. This scheme requires the existence of a third party, also called a service provider in cloud computing, to manage the relationship. The relationships in cloud computing creates many security and privacy gaps. Thus, security in cloud computing is mainly focused on protection and the guarantee of data transmission security.

Knowing who the users are and what services are equipped by the cloud is important in understanding the risks of and threats to data storage over the cloud. Youseff et al. (2008) defined users (also called clients or customers) as individuals, companies or governments seeking the use of infrastructure and services over the cloud, whereas service providers are individuals, companies or governments with abilities to offer infrastructure and services for general consumption.

Modern cloud computing technology has enabled the access of required resources, such as servers, applications, network and services. The process utilizes common computing models based on data traffic, in which a third party handles the regulation (Kumar and Vajpayee, 2016). Security and privacy remain the major challenge in handling sensitive information in the cloud environment (Loganayagi and Sujatha, 2012). Sensitive information is defined as data that must be protected from unauthorised access to safeguard the privacy and security of individuals or organisations (Rouse, 2014).

Sensitive data represent the data related to a person or an organization, such as social security number, driver's license number, credit card number, medical and health data, financial data or confidential legal and personally identifiable information (PII). PII, including name, address, phone number or e-mail address, is a type of information that identifies a person and can be used to identify or locate a person. The three main types of sensitive data are *personal information*, *business information* and *classified information* (Rouse, 2014).

This study is conducted to seek the factors affecting sensitive data and the transmission of information by public cloud domain management. Subsequently, a framework for the effective decision making of information systems is proposed for the management of sensitive data and private information.

1.2 Research Problem

Managing data security and privacy is difficult, but the situation is more difficult in cloud computing. The cloud environment is intangible, and data are handled by software dispersed from the user's location. Thus, privacy and security are a major challenge for many companies and users (Loganayagi and Sujatha, 2012). The above problems can be explained in three aspects: data, privacy and security and persons or companies:

The first aspect related to data can be further divided into three issues.

- i. Data integrity:* This aspect may include cases, such as error cases, when data are transmitted from one place to another or from one computer to another. The other possible issue is exposure to hardware and system malfunctions, such as viruses or crashed disks (Anitha, 2013).
- ii. Data access control:* Private data can be accessed illegally due to the lack of access control to confidential data. The accessibility of sensitive data in the cloud computing environment is regarded a security challenge and thus needs to be addressed (Anitha, 2013).
- iii. Loss of data and stolen data:* Cloud computing is used to process and store data on external servers for cost-effective and flexible operation. However, this feature opens opportunities for data theft, which is a serious problem in cloud computing, especially with financial or banking transactions (Anitha, 2013).

The second aspect is related to privacy and security.

- i. Protection and privacy:* The security of personal information is extremely important in cloud computing. Most servers are located externally, which implies that vendors must ensure the security of information from other operators (Anitha, 2013).
- ii. Infected and malicious applications:* A service provider needs to have the full right to use the server for the purpose of observing and preserving the server (Anitha, 2013). This scheme can prevent intruders from sending infected applications to the cloud; moreover, this problem will strongly affect cloud service and client service (Anitha, 2013).

The third aspect is related to persons or companies.

- i. User-level security issues:* Users must ensure that their own data can be protected from losses or manipulation by other users in the same cloud (Anitha, 2013).
- ii. Provider-level security issues:* Providers should install layers of security features for customers and users (Anitha, 2013).

Most approaches and processes in the previous research to assure data privacy (DP) are limited to common methods, such as data encryption, that require high time and space costs for data storage, which subsequently lead to slow transmission speed for data storage and retrieval. The encryption technology also needs alternative encryption keys to reduce risks against unauthorized detection and penetration, which may lead to data breach (Xu et al., 2013; Gupta et al., 2014; Liu et al., 2014; Tebaa and Hajji, 2014; Zhao et al., 2014; Jogdand et al., 2015).

This research addresses all the above three issues related to data or information protection against malicious insiders (Zhou, 2013; Chintawar and Ismail, 2014), security issues due to breaches and losses (Khan, 2013; Daniel, 2014; Liu et al., 2014) and loss of privacy of sensitive data of organizations and users who transmit data over the public cloud domain, especially because the cloud environment is used to process and store data.

1.3 Research Questions

The following questions are forwarded in this research, which is about sensitive data management over the public cloud domain, for the effective decision making of information systems:

- 1- How can privacy and sensitive data transmission management be effectively achieved in public cloud computing?
- 2- What policy attributes and factors are needed to manage sensitive data in cloud computing?
- 3- How can the factors be effectively combined into a method to manage sensitive data in cloud computing?

1.4 Research Objectives

The main objectives of this research are as follows:

- 1- To propose a multi-level framework (MLF) to enhance the privacy of sensitive data and prevent data breach and data loss.
- 2- To define the main factors that affect the decision making of information systems for the management of sensitive data transmission.
- 3- To develop a tool to manage the transfer of sensitive data to cloud-computing storage space.

1.5 Research Motivation

The review of previous studies highlights the importance of protecting and managing sensitive data in cloud computing. Considering that the three aspects are inadequately studied from the MIS perspective in the previous research, the present study is motivated to provide a framework for data protection, privacy and security from the MIS perspective.

1.6 Research Contributions

This research offers the following contributions:

- i. The factors that affect the decision making of information systems for sensitive data management in cloud computing environments are defined.
- ii. A framework to enhance the management of sensitive data in cloud environments is verified.
- iii. A tool to support and prove the framework is proposed.
- iv. The results of an experimental test are used as evidence to prove that the proposed framework can effectively manage sensitive data.

1.7 Research Scope

This research is scoped down to protect transmissions for sensitive and private data in public cloud environment. The protection covers attacks from malicious insiders, security breaches and data losses from private and confidential files to public clouds. Due to many available factors for the management and protection of sensitive data, which are not pertinent to the study scope, therefore, this study only focuses on confidentiality, integrity, privacy and availability factors. Public cloud environment is the domain for this study as it is popularly used to process and store data, including private and confidential data.

1.8 Thesis Organization

This thesis is divided into seven chapters. The first chapter is about the introduction and explains briefly the problem statement, research questions, research objectives and research contribution.

Chapter 2, which is about the literature review, presents the definition of cloud computing and discusses its characteristics, technology and security and compliance. Chapter 2 also includes a discussion about MIS and its decision-making process and the scope of this research.

Chapter 3 describes the research methodology, including the justification of the research design, population and sample, instrumentation and data collection and analysis.

Chapter 4 describes the design and the implementation of the new proposed MLF and its practical applications.

Chapter 5 presents the analysis of the results, the validation results, and related discussions.

Chapter 6 concludes the research and presents recommendations for future research.

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