UNIVERSITI PUTRA MALAYSIA

IMPROVED TLS PROTOCOL FOR PLATFORM INTEGRITY ASSURANCE USING MUTUAL ATTESTATION

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By

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Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Master of Science

July 2014

DEDICATIONS

To my beloved husband, Mohd Iskandar bin Idris,

To my lovely mother, Jamiah binti Bero,

And to the memory of my late father, Abd Aziz bin Hassan,

passed away peacefully on 3 December 2012.

May Allah bless his soul, and grant him the highest level of paradise...Ameen.

Al-Fatihah.

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Master of Science.

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NORAZAH BINTI ABD AZIZ

July 2014

Chair: Associate Professor Nur Izura Udzir, PhD

Faculty: Computer Science and Information Technology

Normally, secure communication between client-server applications is established using secure channel technologies such as Transport Layer Security (TLS). TLS is a cryptographic protocol which ensures secure transmission of data and authenticity of communication at each endpoint platform. However, the protocol does not provide any trustworthiness assurance of the involved endpoint. So, they are not able to handle the security risks due to potential malicious software or any third parties who may penetrate the platform. Furthermore, there is no mechanism for a computing platform to address the trustworthiness of platform integrity such as free from any malware or spyware.

Remote attestation is an authentication technique proposed by the Trusted Computing Group (TCG) which enables the verification of the trusted environment of platforms and assuring the information is accurate. To incorporate this method in web services framework in order to guarantee the trustworthiness and security of web-based applications, a new framework called TrustWeb is proposed. The TrustWeb framework integrates the remote attestation into TLS protocol to provide integrity information of the involved endpoint platforms. The framework improves TLS protocol with mutual attestation (MA) mechanism, named TLS+MA which can help to address the weaknesses of transferring sensitive computations, and a practical way to solve the remote trust issue at the client-server environment.

In this thesis, we study the foundations of the credibility of the TLS+MA protocol and TrustWeb approach before we describe the work of designing and building a framework prototype in which attestation mechanism is integrated into the Mozilla Firefox browser and Apache web server. We analyse the security of our protocol using Automated Validation of Internet Security Protocols and Applications (AVISPA) to show that it meets the security goals. Analysis on TLS+MA protocol shows that it is resistant against replay and collusion attacks. For performance analysis, we also compared the TLS+MA with previous protocol. The results show that our protocol only incurs 11.2% of performance overhead in secure connection, which lower than the previous protocol. Despite that, our protocol is 50% more efficient.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk Ijazah Sarjana Sains.

PENAMBAHBAIKAN PROTOKOL TLS MENGGUNAKAN PENGAKUSAKSIAN BERSAMA BAGI JAMINAN INTEGRITI PLATFORM

Oleh

NORAZAH BINTI ABD AZIZ

Julai 2014

Pengerusi: Profesor Madya Nur Izura Udzir, PhD

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Kebiasaannya, keselamatan komunikasi antara perisian pelayan-pelanggan dibangunkan dengan menggunakan teknologi keselamatan rangkaian seperti Keselamatan Lapisan Pengangkutan (*Transport Layer Security (TLS)*). TLS adalah protokol kriptografi yang memastikan keselamatan data dan komunikasi yang sah di setiap destinasi platform. Namun, protokol ini tidak menawarkan sebarang jaminan kebolehpercayaan bagi setiap platform titik hujung yang terlibat. Dengan itu, protokol ini tidak berupaya menangani sebarang risiko keselamatan yang diakibatkan oleh serangan perisian hasad atau pihak ketiga yang mungkin telah menembusi platform. Tambahan pula tiada mekanisma untuk sesebuah platform pengkomputan menentukan kebolehpercayaan integriti platform sama ada ia bebas daripada sebarang perisian hasad atau perisian perisikan.

Pengakusaksian jauh adalah satu teknik pengesahan yang dicadangkan oleh Trusted Computing Group (TCG) yang membolehkan pengesahan persekitaran yang boleh dipercayai bagi sesebuah platform dilakukan dan memastikan maklumat yang diperolehi adalah tepat. Untuk menggabungkan kaedah ini dalam rangka kerja perkhidmatan web bagi menjamin kebolehpercayaan dan keselamatan aplikasi berasaskan web, satu rangka kerja baharu yang dipanggil TrustWeb telah dicadangkan. Rangka kerja TrustWeb ini mengintegrasi komponen pengakusaksian jauh ke dalam protokol TLS bagi menyediakan maklumat integriti bagi sesebuah platform titik hujung yang terlibat. Rangka kerja ini menambahbaik protokol TLS dengan mekanisma pengakusaksian bersama yang dinamakan TLS+MA yang mana dapat membantu menangani masalah kelemahan dalam memindahkan maklumat pengiraan yang sulit dan merupakan cara yang praktikal untuk menyelesaikan isu kebolehpercayaan jauh

dalam persekitaran pelanggan-pelayan.

Dalam tesis ini, kami mengkaji asas-asas kredibiliti protokol TLS+MA dan pendekatan TrustWeb sebelum kami menerangkan mengenai reka bentuk dan pembinaan prototaip rangka kerja di mana mekanisma pengakusaksian disepadukan ke dalam pelayar Mozilla Firefox dan pelayan web Apache. Kami membuat analisa keselamatan pada protokol kami menggunakan Automated Validation of Internet Security Protocols and Applications (AVISPA) untuk menunjukkan bahawa ia memenuhi matlamat keselamatan. Analisa pada protokol TLS+MA itu juga kebal daripada serangan Replay dan Collusion. Bagi analisa prestasi, kami membuat perbandingan penyelesaian rangka kerja diantara TLS+MA dengan protokol terdahulu. Keputusan menunjukkan bahawa protokol kami hanya mengalami penurunan prestasi dalam keselamatan rangkaian sebanyak 11.2% sahaja. Sehubungan dengan itu, menunjukkan bahawa protocol kami 50% lebih efisien.

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Last but not least, I dedicate special thanks to my mother, siblings and friends who had encouraged me throughout my journey in pursuing this master degree.

I certify that a Thesis Examination Committee has met on 22 July 2014 to conduct the final examination of Norazah binti Abd Aziz on her thesis entitled "Improved TLS Protocol for Platform Integrity Assurance using Mutual Attestation" in accordance with the Universities and University Colleges Act 1971 and the Constitution of the Universiti Putra Malaysia [P.U.(A) 106] 15 March 1998. The Committee recommends that the student be awarded the Master of Science.

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I hereby confirm that:

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Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: _____	Signature: _____
Name of Chairman of Supervisory Committee: _____	Name of Member of Supervisory Committee: _____

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LIST OF ABBREVIATIONS

AIK	Attestation Identity Key
BIOS	Basic Input/Output System
CA	Certificate Authority
CGI	Common Gateway Interface
COT	Chain of Trust
CPU	Central Processing Unit
CRTM	Core Root of Trust for Measurement
cURL	Client URL Request Library
DAA	Direct Anonymous Attestation
EK	Endorsement Key
HTML	Hypertext Markup Language
HLPSL	High Level Protocol Specification Language
HTTPS	Hyper Text Transfer Protocol Security
IDS	Intrusion Detection System
IETF	Internet Engineering Task Force
IMA	Integrity Measurement Attestation
IPsec	Internet Protocol Security
MA	Mutual Attestation
MITM	Man-in-the-Middle
NAT	Network Address Translation
NSS	Network Security Service
OASIS	Organization for the Advancement of Structured Information Standards

PCA	Privacy CA
PCR	Platform Configuration Register
RA	Remote Attestation
RSA	Cryptosystem (Ron Rivest, Adi Shamir, Leonard Adleman)
RTM	Root of Trust for Measurement
SOAP	Simple Object Access Protocol
SML	Storage Measurement List
SSL	Secure Socket Layer
TCG	Trusted Computing Group
TCPA	Trusted Computing Platform Alliance
TLS	Trusted Layer Security
TNC	Trusted Network Connect
TPM	Trusted Platform Module
TSS	TCG Software Stack
TTP	Trusted Third Party
URL	Uniform Resource Locator
VPN	Virtual Private Network
WSDL	Web Service Definition Language
XACML	EXtensible Access Control Markup Language

CHAPTER 1

INTRODUCTION

This chapter presents as an overview of the authenticated key exchange with platform integrity assurances framework which comprises of extended Secure Socket Layer (SSL) or TLS protocol with mutual attestation. In this chapter, we describe the motivation of the framework in Section 1.1. Section 1.2 states the problem being solved followed by Section 1.3 which lists thesis objective. The scope of the research is defined in Section 1.4. In Section 1.6, we summarize the main thesis contribution. Finally, Section 1.7 outlines the organization of the thesis.

1.1 Motivation

With the rapid increase in remote services such as e-commerce and online systems usage, online transactions security becomes more crucial. In order to protect data communication on the network, many remote services are dependent on the deployment of SSL/TLS protocol. SSL/TLS supports security schemes with authentication, data integrity and confidentiality between two networking applications. Most SSL/TLS implementations utilize remote authentication scheme to validate the host's identity across the network by using public-key certificate mechanism. However, improper key exchange mechanism and unknown integrity status of the host's platform might expose sensitive information to an attacker. So, SSL/TLS is still vulnerable to remote attacks because the protocol is unable to provide integrity of remote system platform. The famous remote attack is phishing attack.

Phishing is a semantic attack which can be categorized into different types of attacks. These attacks' behaviour depends on the diverse type of proliferation including man-in-the middle (MITM) and malware. Man-in-the-middle attack is a class of phishing attack which spoof a browser using phishing email or bogus web sites to lure user into unknowingly produce user information such as usernames, passwords and account details. All the information can be used for criminal purposes by impersonating the user. This attack exploits weaknesses in client-server authentication schemes such as password authentication and SSL/TLS implementation. In contrast, malware-based attacks using malicious pieces of software installed on the host platform to steal confidential information. The malware is installed through drive-by installations technique. The techniques use online advertising spaces or faulty websites to publish hidden malicious HTML code by exploiting popular website vulnerabilities. The malware is automatically installed on the platform when users browse to the website.

In order to protect against these attacks, there are a number of security solutions for phishing defences have been introduced. The famous security solutions are using end-system security product such as malware scanners and personal firewall [33]. The installation, maintenance and correct usage of these security products rely on end user capability. It may require extensive configuration effort and high

technical skill. However, the configuration process will confuse non-technical users and can cause insufficient configuration that lead to reduce product functionalities. Furthermore, most of these security products are costly. Other well-known security solutions are password authentication scheme and SSL/TLS protocol. As discussed earlier, there are also weaknesses in these solutions due to the lack of a proper mechanism to establish the integrity and non-repudiation requirements of the information involved in online transactions [33].

As a result, existing computing platforms are exposed to various security problems due to the weaknesses of the hardware architecture and software configuration complexity. So, in order to guarantee authenticity, integrity, privacy, anonymity or availability of the computing platform, there are initiatives proposed by [25, 61] to use Trusted Platform Module (TPM) functionalities to verify the security of the platform. TPM is a hardware security chip introduced by the Trusted Computing Group (TCG). TCG is a non-profit industry standardization organization that aims to develop and promote an open industry standard to enhance the security of the trusted computing hardware and software building blocks. TCG has produced the specification for TPM (TPM specification 1.2). In the specification, clear guideline and explanation are given, so that developers can easily develop a system which uses the TPM [76]. In accordance with other security hardware extensions [17, 18], the TPM is embedded with cryptographic mechanisms that can be used to remotely certify the integrity of the application or system running on the platform. This functionality adopts attestation method to establish integrity assurance of the state of the hardware and software running on the computing device.

Remote attestation is a method which a client authenticates its hardware and software configuration to a remote host. Remote attestation enables a client to verify the identity and platform integrity of a remote host and vice versa. Moreover, the remote attestation's purpose is to ensure the trustworthiness of a platform without revealing the actual properties and configuration of the platform. Hence, this method provides confidence to client and remote host to communicate across a network through web services.

1.2 Problem Statement

Web services are the most established mechanism to support interaction between host platforms over a network. So, it is important to provide better security solutions on the web service applications platform. Although TLS protocol is widely used to secure network communication, normal TLS protocol does not handle the endpoint integrity issue. Hence, it is necessary to enhance the security of TLS communication by platform integrity assurance between client and remote host to ensure no malware or spyware is installed.

As mentioned earlier, even with security provided by TLS on the web services environment, web client have no assurance about the integrity of server platforms and

vice versa. Due to that, mechanisms are needed to provide the web server with trusted features which promises high security assurance. But how about in the situation wherein the web server has been compromised and consequently violates the integrity of clients information? The feasible solutions to this issue require Trusted Third Party (TTP) involvement to verify the integrity status of the web client and server.

Trusted computing techniques introduce a security mechanism via the TPM, a tamper-resistant hardware to provide integrity protection functionalities for web services platform. Other than securing cryptographic key in a protected storage, the TPM is also utilized to attest the web services platforms configuration. The mechanism is known as Remote Attestation (RA). An attestation technique is an essential mechanism to ensure a particular platform of endpoint has not been tampered with and is in a trusted state. Hence, this mechanism will be used to guarantee the hosts trust level before transmitting any sensitive information to remote host. Then, to assure the communication partner of web services environment, the RA requires verification method such as the TTP.

However, the RA mechanism which transfers the clients system components measurements to the remote host faces some challenges [27, 72, 71]. The challenges include on how to establish and secure the attestation channel between the client and remote host without neglecting scalability issues [71]. So, it is important to establish the attestation communication in a well-defined security protocol, otherwise, the attacker might be able to relay attestation challenge of compromised host to another host and masquerade the host as a trusted one [72].

In view of the issues above, this thesis proposes an integrated security solution for web services that extend SSL/TLS with remote attestation protocol. The idea is to develop a framework of dynamic software-oriented and fine-grained attestation in web environment called "TrustWeb" which leverages on TCG and web security technologies. Furthermore, all the proposed protocols embed the attestation protocol in the TLS extension resulting in modification of TLS library and hence changes plug-ins in users browser or application. Our protocol is designed in such a way that the TLS library does not have to be modified.

1.3 Research Objective

The main objective of the research is **to propose an improved TLS protocol to achieve platform security assurance and trustworthiness of the platform in client server environment** whilst considering the following requirements.

1. Security

   The major motivation of TrustWeb is to enhance web security by utilizing the capability of mutual remote attestation in isolated web environment. This approach which integrates TLS protocol with attestation mechanism will allow web server to verify the integrity of a requesting web client before permitting an access to a protected object based on integrity evidence and information of the web client. The web client can also verify the integrity of the web server before performing any transaction. The TrustWeb protocol will achieve some of the existing TLS security goals which are:

   - Confidentiality
   - Entity and data origin authentication
   - Data integrity
   - Privacy
   - Unlinkability

   and new security goal which is:

   - Platform Integrity

2. Performance

   The TrustWeb approach enhances the current web communication model by introducing extra entities and extra steps into the authentication phase. As a result, this approach is expected to degrade Web servers' performance level. Furthermore, SSL-enabled host is generally slower than non-SSL host. This approach is expected to achieve more security at the cost of performance degradation since adding more security inevitably incurs overhead. However, the approach must minimize the performance degradation to be widely accepted by the industrial world.

1.4 Scope

The scope of this research work is outlined in the following points:

1. The framework and implementation being discussed in this research work focus on web-services platform because it is most commonly used in client-server environment. However, major component of the framework can be implemented in any other client-server applications.

2. The security goals focused in this research work are confidentiality, entity authentication, data origin authentication, privacy, unlinkability, data and platform integrity. This can be achieved with existing TLS version and mutual attestation mechanism. Hence, other security goal such as client anonymity is beyond the scope of this thesis.

3. Security analysis of the protocols is performed using Automated Validation of Internet Security Protocols and Applications (AVISPA) with Dolev-Yao security model. The strength of the protocols against replay and collusion attack is also investigated through informal analysis.

4. The certification authorities mechanism used in this work is assumed secure and trusted. The discussion of this mechanism limitation is beyond the scope of this thesis.

5. The implementation of TrustWeb framework were developed for Mozilla Firefox and Apache as client and server applications, respectively. The solution framework is compared against other protocols to measure it time efficiency.

1.5 Significance of Study

The significance of this research work is outlined in the following points:

1. Provides **security protection** for secret information inside web client or server host from being revealed to any adversary.

2. Provides **integrity check** within SSL/TLS protocol so that it is resistant from being attack by adversary or untrusted system.

3. Provides **integrity measurement** for web applications running on SSL/TLS protocol so that it can detect any compromised application.

4. Provides **end-point integrity assurance** in web services environment.

1.6 Contributions

This thesis makes the following contributions:

1. **Extended TLS protocol, TLS+MA to achieve the endpoint integrity of client and server platform.**
   The TLS authenticated key exchange is extend with mutual attestation mechanism which provides protection against major active attacks such as replay attack, malicious code attacks and man-in-the-middle attacks.

2. **Another protocol, TLS+CA sets up secure communication with unilateral attestation.**
   In this protocol only client's platform integrity is verified. The advantage of this protocol is that the client achieves anonymity against the server.

3. **An implementation of TrustWeb framework that involves the TLS+MA protocol between web browser and web server.**
   The implementation consist of :

- A novel pluggable interfaces used to perform remote attestation which can be customized either to embed with or integrate with TLS protocol in client-server environment.
- Additional module for Certificate Authority (CA) which provide Endorsement Key (EK) credential as authoritative certificate of TPM.

1.7 Organization of Thesis

This thesis is organized in accordance with the standard structure of thesis at Universiti Putra Malaysia:

Chapter 2 Literature Review provides relevant information about Trusted Computing technology in order to create a basis of understanding for the rest of the thesis. This chapter also summarize methods used in related work which the design structures and security strengths are compared as well as the necessity of combining the TLS with attestation in a client-server environment.

Chapter 3 Research Methodology describes the research methodology on how to conduct this research including method of verification that will be used to analyze the security of the proposed protocol.

Chapter 4 Extending TLS Protocol briefs about attestation protocol design and component that are directly related to our proposed protocol.

Chapter 5 Security Analysis of Protocol presents the security analysis of the proposed protocol in Chapter 4.

Chapter 6 Implementation of TrustWeb contains the detail of TrustWeb framework and implementation based on the proposed protocol.

Chapter 7 Performance Analysis of TrustWeb presents the performance result analysis of TrustWeb framework implementation in Chapter 6.

Chapter 8 Conclusions and Future Works concludes the thesis and presents possible directions for future work.

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