

Cryptanalysis of Multi-Server Authenticated Key Agreement Scheme Based on Trust Computing Using Smart Cards and Biometrics

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Abstract

Advancement in communication technology provides a scalable platform for various services where a remote user can access the server from anywhere without moving from its place. It has provided a unique opportunity for online services, such that the user need not physically present at the service center. These services adopt authentication and key agreement protocols to ensure authorized and secure access to resources. Most of the authentication schemes support single server environment where the user has to register with each server. If a user wishes to access multiple application servers, he requires to register with each of the servers. Although multi-server authentication schemes introduced a scalable platform such that a user can interact with any server using single registration. Recently, Chuang and Chen proposed an efficient multi-server authenticated key agreement scheme based on smart cards along with password and biometrics. This is a lightweight authentication scheme which requires the computation of only hash function. In this article, we present a brief review of Chuang and Chen's scheme. We analyze Chuang and Chen's scheme and identify that their scheme does not resist stolen smart card attack which causes the user's impersonation attack, server spoofing attack and man-in-the middle attack. Additionally, we show that their scheme has a weak key agreement protocol, which does not ensure forward secrecy.

keywords: Network Security; Multi-server communication; Smart card; Biometric based authentication; Anonymity.

1 Introduction

The advances in communication technology are enhancing the quality of online services. As a result, the Internet is emerging a scalable platform for various services where users and service providers are realizing its importance. This provides a unique opportunity to the users, such that they can access the remote servers at anytime and from anywhere.

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However, the user interacts with the server via public channel where an adversary is considered to be enough powerful that he can control over the public channel, such that he can eavesdrop, intercept, modify, delete, and replay the transmitted message via public channel. This causes a serious threat to the data security and integrity. At the same time, the authenticated key agreement protocols provide secure and authorized communication between remote entities. The smart card based authentication protocols are designed and developed to provide authorized and secure communication between the remote user and the server.

Most of the existing authentication protocol only supported a single server environment [1]. However, a user may wish to access multiple application servers at the same time for various of kinds of application. Therefore, if the authentication scheme does not support the multi-server environment, the user has performed the registration on each of the servers. This makes the system very complex from the user point of view and a user may leave the system.

Most of the existing schemes that support multi server environment are password based [2]. The password based authentication schemes provide two-factor remote user authentication while biometrics based user authentication schemes provide three-factor authentication. Moreover, uniqueness property of biometric increases its application in authentication protocols. Therefore, biometric-based remote user authentication schemes have attracted significant research attention. The Biometric based schemes have the advantages of biometric keys (fingerprint, face, iris, hand geometry and palm-print, etc.), which are as follows:

- (1) Biometric keys do not need to remember.
- (2) Biometric keys cannot be easily guess.
- (3) Biometric keys maintain the uniqueness property.

In 2010, Yang and Yang [3] proposed biometric-based multi-server authentication schemes. However, there scheme computational cost is high, as it needs to perform exponential operations. In 2011, Yoon and Yoo [4] also presented a biometric-based authenticated key agreement scheme for multi-server environment. Although He [5] pointed out the vulnerabilities of Yoon and Yoo's scheme to insider attacks, masquerade attacks and loss of smart card attacks. Moreover, both the schemes fail to protect user's privacy. Recently, Chuang and Chen [6] proposed an anonymous multi-server authenticated key agreement scheme based on smart cards along with password and biometrics. Their scheme provides an efficient solution for multi-server environment, where a user interact with any server using single registration. In this article, we present a brief review of Chuang and Chen's scheme. We also present cryptanalysis of Chuang and Chen's scheme and show that their scheme does not resist stolen smart card attack which causes the user's impersonation attack, server spoofing attack and man-in-the middle attack. Additionally, we saw that their scheme has a weak key agreement protocol, which does not ensure forward secrecy. The rest of the paper is organized as follows: Section 2 presents the brief review of Chuang and Chen's scheme. Section 3 points out the weaknesses of Chuang and Chen's scheme. Finally, the conclusion is drawn in Section 4.

2 Review of Chuang and Chen's Scheme

Recently, Chuang and Chen [6] proposed an anonymous authentication scheme using biometric-based smart card. In this section, we will briefly discuss the Chuang and Chen's scheme, in which we try to use the same terminology as presented in their article.

2.1 Server registration phase

The application server sends a registration request to the registration center if he wishes to be become authorized server in the system. Then, registration center authorized the server and provides the key PSK to the server using Key Exchange Protocol (IKEv2) [7]. Upon receiving the secret key PSK , the authorized server uses this key to authorize the legitimate user.

2.2 Registration Phase

Step 1. The user U computes $h(PW_i \oplus BIO_i)$ and sends his registration request with ID_i and $h(PW_i \oplus BIO_i)$ to the registration center via secure channel.

Step 2. The registration center computes $A_i = h(ID_i||x)$, $B_i = h(A_i) = h^2(ID_i||x)$, $C_i = h(PW_i \oplus BIO_i) \oplus B_i$ and $D_i = PSK \oplus A_i$.

Step 3 Registration center personalizes the user's smart card by including the parameters $\{ID_i, B_i, C_i, D_i, h(\cdot)\}$ and provides the personalized smart card to the user via a secure channel.

2.3 Login Phase

To start the login session, the user inserts his smart card into the card reader and inputs his identity ID_i and password PW_i , and imprints his biometric information BIO_i at the sensor. Upon receiving the input, the smart card executes the login session as follows:

Step 1. Verify ID_i and $B_i \stackrel{?}{=} h(PW_i \oplus BIO_i) \oplus C_i$. If the verification succeeds, it executes the next step.

Step 2. Generate a random number N_1 and compute $M_1 = h(B_i) \oplus N_1$, $AID_i = h(N_1) \oplus ID_i$ and $M_2 = h(N_1||AID_i||D_i)$.

2.4 Authentication Phase

Step 1. The smart card sends the authentication request with the message $\langle AID_i, M_1, M_2, D_i \rangle$ to the server.

Step 2. Upon receiving the message $\langle AID_i, M_1, M_2, D_i \rangle$, server S uses its pre-shared key PSK and achieves $A_i = D_i \oplus PSK$. The server also retrieves $N_1 = h(B_i) \oplus M_1$ and $ID_i = AID_i \oplus h(N_1)$.

Step 3. The server verifies $M_2 \stackrel{?}{=} h(N_1 || AID_i || D_i)$. If verification holds, the server generates a random number N_2 and computes the session key $SK_{ij} = h(N_1 || N_2)$.

Step 4. The server computes $M_3 = N_2 \oplus h^2(N_1)$ and $M_4 = h(SID_j || N_2)$ and responds with the message $\langle SID_j, M_3, M_4 \rangle$ to the smart card.

Step 5. Upon receiving the message $\langle SID_j, M_3, M_4 \rangle$, the smart card retrieve the value $N_2 = M_3 \oplus h^2(N_1)$. Then, it verifies $M_4 \stackrel{?}{=} h(SID_j || N_2)$. If verification holds then computes the session key $SK_{ij} = h(N_1 || N_2)$.

Step 6. The smart card computes $M_5 = SK_{ij} \oplus h(N_2)$ and sends M_5 to the server.

Step 7. Upon receiving $\langle M_5 \rangle$, the server verifies $h(N_2) \stackrel{?}{=} M_5 \oplus SK_{ij}$. If the varication holds, the mutual authentication completes.

2.5 Password change phase

The legal user can change his password without the help of server as follows:

Step 1. A user inputs his identity ID_i and PW_i , and imprints his biometric BIO_i at the sensor.

Step 2. The smart card verifies ID_i and $B_i \stackrel{?}{=} h(PW_i \oplus BIO_i) \oplus C_i$. If the verification does not succeeds, the smart card rejects the request. Otherwise, the user can enter a new password PW_i^* .

Step 3. The smart card computes $C_i^* = C_i \oplus h(PW_i \oplus BIO_i) \oplus h(PW_i^* \oplus BIO_i)$ and replace C_i with C_i^* .

3 Cryptanalysis of Chuang and Chen's Scheme

In this section, we analyze Chuang and Chen's scheme and demonstrate some of the attacks.

3.1 Stolen smart card attack

An efficient biometric based multi-server authentication protocol must not allow an adversary to misuse user's stolen smart card to login to the server or to compute established session keys without knowing the user's biometric and password. Here, we show that Chuang and Chen's scheme fails to resist stolen smart card, such that an adversary can achieve user's long term secret key and can easily login to the server as a legitimate user using stolen smart card. Additionally, an adversary can achieve previously established session keys. This creates the data security and integrity threat as user and server protect their confidential data during data transmission using the session key and if session key is compromised, an adversary can achieve all the data that have been transferred between the user and server. The stolen smart card attack executes on Chuang and Chen's scheme as follows:

- An adversary can achieve the stored parameters $\{ID_i, B_i, C_i$ and D_i from the smart card using existing techniques, such as power analysis attack, differential attack etc.
- An adversary can intercept and record all the previously transmitted message $M_1 = h(B_i) \oplus N_i$ and $M_3 = N_2 \oplus h^2(N_1)$.
- The adversary can achieve the values $N_1 = M_1 \oplus h(B_i)$ and $N_2 = M_3 \oplus h^2(N_1)$.
- Using the values N_1 and N_2 , the adversary achieve the session key SK_{ij} as $SK_{ij} = h(N_1||N_2)$.

It is clear from the above discussion that an adversary can achieve all the previously established session key using the stolen smart card. Using the compromised session key, an adversary can achieve all the confidential data that is transferred between user and server as exchanged data is being protected by established session key and an adversary can eavesdrop and intercept all the transmitted message between user and server.

3.1.1 User's Impersonation attack

An adversary can also successfully login to the server using the stolen smart card without having the user's biometric imprint and password as follows:

- An adversary can achieve the stored parameters ID_i, B_i and D_i from the smart card.
- The adversary generates a random number N_E and computes $M_{1E} = h(B_i) \oplus N_E$, $AID_E = h(N_E) \oplus ID_i$ and $M_{2E} = h(N_E||AID_E||D_i)$. He masquerades as a legitimate user U and sends the message $\langle AID_E, M_{1E}, M_{2E}, D_i \rangle$ to the server.
- Upon receiving the message $\langle AID_i, M_{1E}, M_{2E}, D_i \rangle$, the server achieves $N_E = h(B_i) \oplus M_{1E}$ and $ID_i = AID_E \oplus h(N_E)$. Then, the server verifies the condition $M_{2E} \stackrel{?}{=} h(N_E||AID_E||D_i)$. The verification holds as $M_{2E} = h(N_E||AID_E||D_i)$. When verification holds, the server generates a random number N_2 and computes the session key $SK'_{ij} = h(N_E||N_2)$.
- The server computes $M_{3E} = N_2 \oplus h^2(N_E)$ and $M_4 = h(SID_j||N_2)$ and sends the message $\langle SID_j, M_{3E}, M_4 \rangle$ to the user U .
- The adversary intercepts the message $\langle SID_j, M_{3E}, M_4 \rangle$ and retrieves the value $N_2 = M_{3E} \oplus h^2(N_E)$ and $SK^*_{ij} = h(N_E||N_2)$. He responds with the message $M_5^* = SK^*_{ij} \oplus h(N_2)$ to the server.
- Upon receiving M_5^* , the server verifies $h(N_2) \stackrel{?}{=} M_5^* \oplus SK'_{ij}$. The verification holds as $SK'_{ij} = SK^*_{ij} = h(N_E||N_2)$. This shows that the adversary successfully masquerade as a legitimate user using the stolen smart card.

3.2 Server spoofing attack

Chuang and Chen's scheme is vulnerable to the server spoofing attack, *i.e.*, an adversary can impersonate the server to the user. The detailed description is as follows:

- The adversary eavesdrops communication between users' and smart card. He intercepts the server's response message $\langle SID_j, M_3, M_4 \rangle$ and achieves server's identity SID_j .
- When the smart card transmits the authentication request with the message $\langle AID_i, M_1, M_2, D_i \rangle$ to the server S via public channel, the adversary intercepts the message. Then, the adversary responds with authorized message using the achieved parameters ID_i and B_i from the stolen smart card as follows:
 - 1.) Compute $N_1 = M_1 \oplus h(B_i)$.
 - 2.) Generate a random number N_E .
 - 3.) Compute $M_{3E} = N_E \oplus h^2(N_1)$ and $M_{4E} = h(SID_j||N_2)$, and responds with the message $\langle SID_j, M_{3E}, M_{4E} \rangle$ to the smart card.
- When the smart card retrieves $N_{2E} = M_{3E} \oplus h^2(N_1)$ and verifies $M_{4E} \stackrel{?}{=} h(SID_j||N_{2E})$. The verification holds as $M_{4E} = h(SID_j||N_2)$.

This shows that an adversary can successfully impersonate as a server.

3.3 Man-in-the middle attack

Chuang and Chen's scheme is vulnerable to the man-in-the middle attack. The justification is as follows:

- When the smart card sends the message $\langle AID_i, M_1, M_2, D_i \rangle$ to the server, the adversary intercepts the message and performs the following steps:
 - i.) Compute $N_1 = M_1 \oplus h(B_i)$.
 - ii.) Generate a random number N_E .
 - iii.) Compute $M_{1E} = h(B_i) \oplus N_E$, $AID_E = h(N_E) \oplus ID_i$ and $M_{2E} = h(N_E||AID_E||D_i)$ then sends the message $\langle AID_E, M_{1E}, M_{2E}, D_i \rangle$ to the server.
 - iv.) Compute $M_{3E} = N_E \oplus h^2(N_1)$ and $M_{4E} = h(SID_j||N_E)$ then sends the message $\langle SID_j, M_{3E}, M_{4E} \rangle$ to the smart card.
- When the server retrieves $N_E = h(B_i) \oplus M_{1E}$ and $ID_i = AID_i \oplus h(N_E)$ and verifies $M_2 \stackrel{?}{=} h(N_1||AID_i||D_i)$. The verification holds as $M_{4E} = h(SID_j||N_E)$. Then the server computes the session key $SK_{Ej} = h(N_E||N_2)$.
- When the server responds with the message $\langle SID_j, M'_3, M'_4 \rangle$, where $M'_3 = N_2 \oplus h^2(N_E)$ and $M'_4 = h(SID_j||N_2)$. The adversary intercepts the message and executes the following steps:
 - a.) Compute $N_2 = M'_3 \oplus h^2(N_E)$ and $SK_{Ej} = h(N_E||N_2)$.
 - b.) Send the message $SK_{Ej} \oplus h(N_2)$ to the server.

- When the server verifies $h(N_2) \stackrel{?}{=} SK_{Ej} \oplus h(N_2) \oplus SK_{Ej}$. The verification holds.
- When the smart card retrieves the value $N_E = M_{3E} \oplus h^2(N_1)$ and verifies $M_{4E} \stackrel{?}{=} h(SID_j || N_E)$. The verification holds as $M_{4E} = h(SID_j || N_E)$. The smart card computes the session key $SK_I = h(N_1 || N_E)$ as the verification holds.
- When the smart card sends $SK_{iE} \oplus h(N_E)$ to the server, the adversary intercept the message.
- The adversary can compute the session key with user and server $SK_{iE} = h(N_1 || N_E)$ and $SK_{Ej} = h(N_E || N_2)$, respectively.

It is clear from the above discussion that an adversary can make independent connections with both the user and server where the user and server believe that they are communicating directly with each other. Moreover, the user and server compute the keys, such that $SK_{iE} \neq SK_{Ej}$. Although the adversary computes both the session keys SK_{iE} and SK_{Ej} .

3.4 Forward secrecy

Chuang and Chen's scheme does not achieve forward secrecy as the adversary can compute established session key with the user's compromised long-term secret key A_i as follows:

- Achieved user's and server's transmitted message $\langle AID_i, M_1, M_2, D_i \rangle$ and $\langle SID_j, M_3, M_4 \rangle$ via public channel, respectively.
- Compute $B_i = h(A_i)$ and retrieve $N_1 = M_1 \oplus h(B_i)$ and then $N_2 = M_3 = N_2 \oplus h^2(N_1)$.
- Compute the session key $SK_{ij} = h(N_1 || N_2)$.

4 Conclusion and future scope

We have shown that an adversary can successfully perform the stolen smart card attack which causes the user's impersonation attack, server spoofing attack and man-in-the-middle attack. We have also demonstrated that Chuang and Chen's scheme does not ensure forward secrecy.

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