# Efficient Two-Pass Anonymous Identity Authentication Using Smart Card

Jue-Sam Chou[1]*, Chun-Hui Huang[2], Yu-Siang Huang[3], Yalin Chen[4]

[1]Department of Information Management, Nanhua University Chiayi 622 Taiwan,
*: corresponding author
jschou@mail.nhu.edu.tw
[2,3]Department of Information Management, Nanhua University Chiayi 622 Taiwan,
[2]g6451519@mail1.nhu.edu.tw
[3]g0069020@mail1.nhu.edu.tw Tel: 886+ (0)5+272-1001 ext.56536
[4]Institute of information systems and applications, National Tsing Hua University
d949702@oz.nthu.edu.tw

**Abstract**

Recently, Khan et al. proposed an enhancement on a remote authentication scheme designed by Wang et al. which emphasizes on using dynamic identity. They claim that their improvement can avoid insider attack. However, we found the scheme lacks the anonymity property. Moreover, R. Madhusudhan et al. indicate their scheme also suffers the insider attack. Due to these observations, in this paper we propose a novel one which not only anonymously authenticates the remote user by using only two passes but also satisfies the ten requirements of an authentication scheme using smart card mentioned by Liao et al..

*Keyword: smart card-based, anonymous verify, insider attack, remote authentication.*

## 1. Introduction

Password-based authentication protocols [1-5, 7-13, 15, 17-24, 26-30, 32-34, 37-38] are widely adopted for logging to remote servers. If designed appropriately, they can provide authentication between the client and the server to assure both parties' legality. However, an attacker may compromise the passwords after their long-time usage. Therefore, a designer usually accommodates such a scheme with password changing function. Most recently in 2013, there are many studies proposed in this field [39-44]. However, other than schemes [6, 17, 22, 31, 39] which are anonymous, all the others in the literature cannot satisfy the three important properties: (1) two passes to reduce the network traffic and increase system performance to be applied in specific circumstances, (2) the anonymity, and (3) the ten security features proposed by Liao et al.. Inspired by this observation, in this paper we attempt to propose such a scheme. In the scheme, we let the secret keys of both the user and the server be x and y, respectively which are embedded in related parameters to complete the three properties. After various security analyses, we found that we can achieve this goal.

The rest of this paper is organized as follows. In Section 2, we review the weakness of Khan et al.'s scheme. Section 3, presents the proposed scheme. Section 4 analyzes its security, and section 5 makes comparisons between our work with some others in the literature and briefly describe its applications. Finally, a conclusion is given in Section 6.

## 2. **Weaknesses in Khan et al.'s and Song's schemes**

Among the related schemes in the literature, Song's [37] claim that their scheme is efficient and strong, but we found the scheme is still vulnerable to password guessing attack if the card is lost, and not anonymous. Both Khan et al. and Wang et al. [1, 23] schemes concern about anonymous identity authentication. They emphasize that their schemes possess the demanded anonymity, but R. Madhusudhan et al.'s [34] found Khan's scheme suffers an insider attack. In addition, we also found it has the smart card lost attack and indeed cannot authenticate anonymously.

- Khan et al.'s scheme is flawed. Because, R. Madhusudhan et al. [34] indicate that it suffers the insider attack. Moreover, we further found an attacker can know $AID_i$ from the transmitted message and thus can obtain the user's identity $ID_i$ by computing $ID_i=AIDi\oplus h(y||T_i||d)$ from the value $y$ stored in the smart card. Therefore, their scheme is not anonymous.
- The song's scheme is vulnerable to smart card lost password guessing attack. Because if an attacker obtains the card, he knows $B_A$. He can then guess the card holders password $PW_A$ as $PW_A$' and compute $K_A$'$=B_A\oplus h(PW_A$'). Then, computes $R_A$''$=D_{KA}$'$(W_A)\oplus T_A$ and compares $h(ID_A||R_A''||T_S)$ with $C_S$. If they are equal, the attacker guesses $ID_A$'s password correctly.

## 3. **Our Proposed Scheme**

From the above mentioned, we know that there still lacks a valid anonymous mutual authentication scheme in the literature. Hence, we propose a novel one to resolve this problem. Our scheme consists of three phases, the registration phase, login and authentication phase, and password change phase. In the following, we first show the used notations and then describe the three phases.

- **Used Notions**

$U$ : the user.
$S$ : the server.
$ID_u$ : the identity of U.
$PW_u$ : the password of U.
$x$ : U's secret value.
y : S's secret value.
$N_s$ : a random number selected by S.
$T$ : the timestamp.

$ID_s$ : the identity of S. $||$ : the concatenation operation.
$C_v$ : a random number selected by U.
$N_u$ : a random number selected by the smart card.
$PW_u'$ : a new password chosen by U in the password change phase.
$pc$ : a random number selected by U for changing password.
$h$ : a collision free one-way hash function, mapping from $\{0,1\}^*$ to $\{0,1\}^n$.

### 3.1 Registration Phase

In this phase, U does the following two steps to register at S for obtaining a smart card.

Step 1. U chooses his $ID_u$, $PW_u$, and two random numbers $C_v$ and $pc$, and computes $u=h(ID_u||PW_u||x)$. Then, he sends $\{C_v, u, x, pc, ID_u\}$ to S through a secure channel.

Step 2. After receiving the message from U, S computes $B=h(ID_s||y||C_v)\oplus h(ID_s||y)$, $A= h(ID_s||y||C_v)\oplus h(ID_s||y)\oplus\ u=h(ID_u||PW_u||x)$, $R=pc\oplus h(ID_u||ID_s||y)\oplus u$, and $O=h(h(pc||u)||h(h(ID_u||ID_s||y)||\ u))$**,** and then stores $\{h(\bullet), ID_u, C_v, A, x, O, R\}$ into the smart card. Later, U will use the parameters $O$ and $R$ to do the password change phase, if he wishes.

The flowchart of registration phase is shown below in Fig. 1.

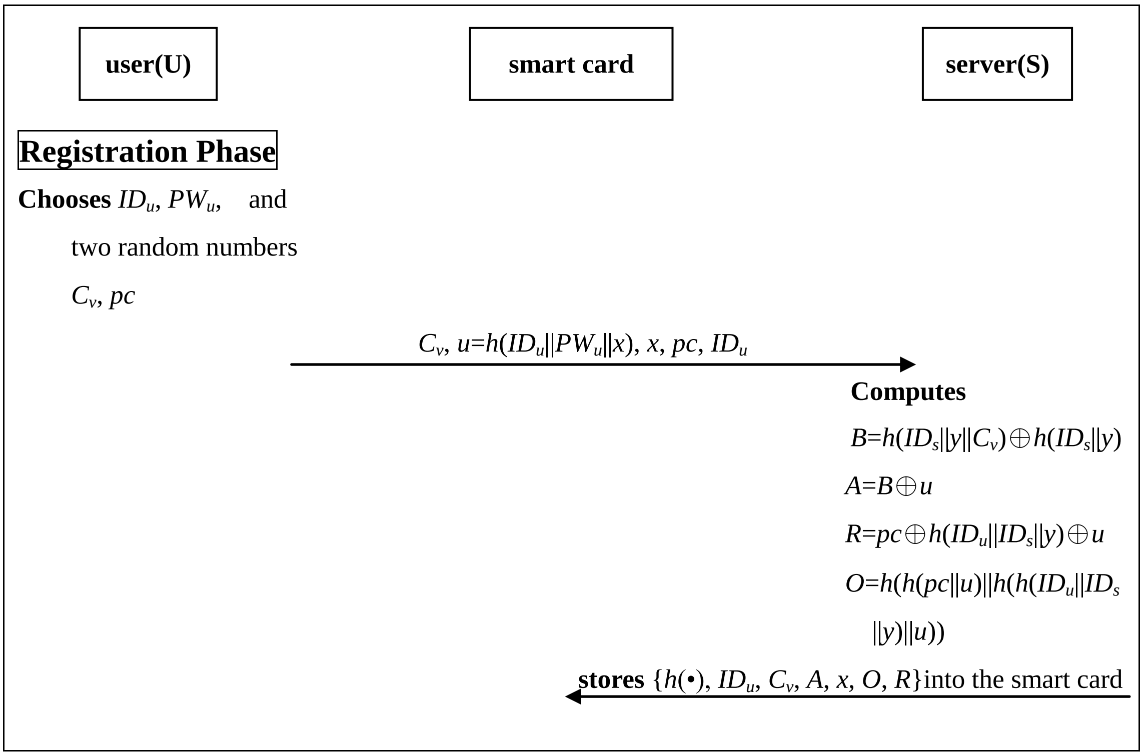

user(U)
smart card
server(S)
Registration Phase
Chooses $ID_u$, $PW_u$, and two random numbers $C_v$, $pc$
$C_v$, $u=h(ID_u||PW_u||x)$, $x$, $pc$, $ID_u$
Computes
$B=h(ID_s||y||C_v)\oplus h(ID_s||y)$
$A=B\oplus u$
$R=pc\oplus h(ID_u||ID_s||y)\oplus u$
$O=h(h(pc||u)||h(h(ID_u||ID_s||y)||u))$
stores $\{h(\bullet), ID_u, C_v, A, x, O, R\}$into the smart card

**Fig. 1. Registration phase**

### 3.2 Login And Authentication Phase

When U wants to login S, he first inserts his smart card and then executes the following steps together with S to do the mutual authentication.

Step 1. The smart card selects a random number $N_u$, computes $u=h(ID_u||PW_u||x)$ and $F=u\oplus N_u$, and acquires the current timestamp $T$ from the system. It then computes $B=A\oplus u$, $N=h(N_u||u)\oplus ID_u$, $M=h(T||u||h(B||N))$, and $Q=h(u||h(N_u||u))$.

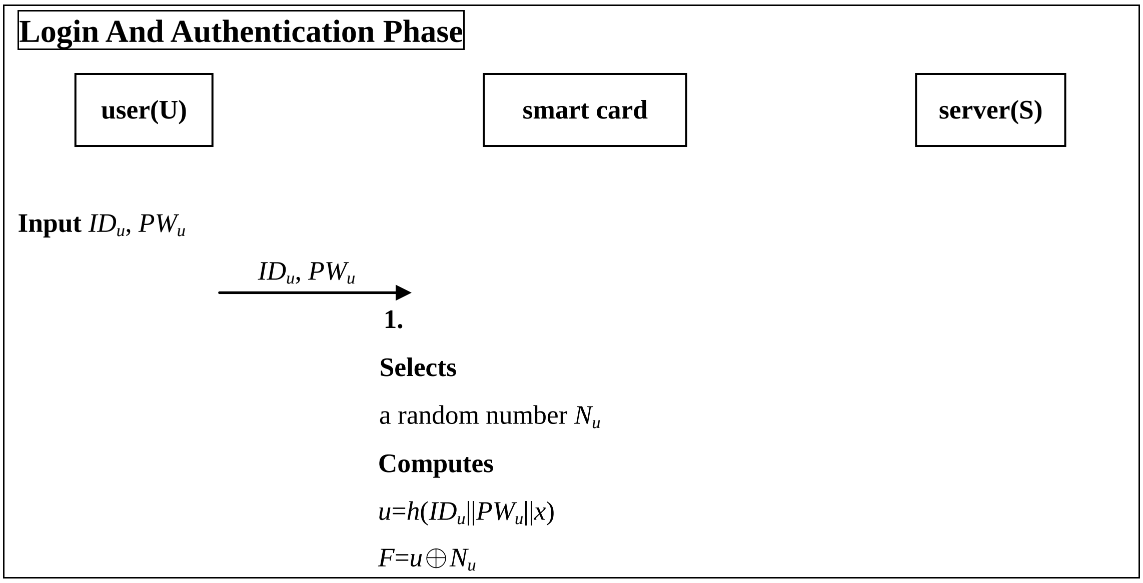
Step 2. Then, U sends message $\{C_v, A, F, M, N, Q, T\}$ to S for the authentication.

Step 3. S checks to see whether $(T'-T)>\Delta T$, where $T'$ is the current system time. If so, S rejects the login request; otherwise, it computes $B'=h(ID_s||y||C_v)\oplus h(ID_s||y)$, $u'=A\oplus B'$, $N_u'=F\oplus u'$, $ID_u=N\oplus h(N_u'\|u')$, and checks whether the equation $Q=h(u'\|h(N_u'\|u'))$ holds. If it holds, S confirms that the values of $ID_u$, $N_u$, and $u$ are valid. It then checks whether equation $M=h(T\|u\|h(B'\|N))$ holds or not. If it holds, S selects a random number $N_s$ and computes $C=h(N_u)\oplus N_s$, $D=h(ID_s||y||N_s)\oplus h(ID_s||y)\oplus u\oplus N_s$, $E=h(N_u||h(N_s))$, and session key $Sk=h(N_u||N_s||u)$.

Step 4. S then sends message $\{C, D, E\}$ to the smart card.

Step 5. Upon receiving the message from S, the smart card computes $N_s'=C\oplus h(N_u)$, and checks if $E=h(N_u||h(N_s'))$ holds. If it holds, the smart card replaces $A$ and $C_v$ by $D\oplus N_s'\oplus h(B)\oplus N_u$ and $N_s'\oplus h(B)\oplus h(N_u)$, respectively for the next login. And then computes the common session key $Sk=h(N_u\|N_s'\|u)$. Now, U and S share the same session key SK.

The flowchart of the login and the authentication phase is shown below in Fig. 2.



**Current** $T$

**Computes**

$B=A\oplus u$

$N=h(N_u\|u)\oplus ID_u$

$M=h(T\|u\|h(B\|N))$

$Q=h(u\|h(N_u\|u))$

**2.**

$\xrightarrow{C_v,\ A,\ F,\ M,\ N,\ Q,\ T}$

**3.**

**Checks** $(T'-T)<\triangle T$, if so

**Computes**

$B'=h(ID_s\|y\|C_v)\oplus h(ID_s\|y)$

$u'=A\oplus B'$

$N_u'=F\oplus u'$

$ID_u=N\oplus h(N_u'\|u')$

$Q\ ?=\ h(u'\|h(N_u'\|u'))$

**Obtains**

$ID_u$, $N_u$, and $u$

**Checks**

$M\ ?=\ h(T\|u\|h(B'\|N))$, if so

**Selects**

a random number $N_s$

**Computes**

$C=h(N_u)\oplus N_s$

$D=h(ID_s\|y\|N_s)\oplus h(ID_s\|y)$
$\oplus u\oplus N_s\oplus h(B)\oplus N_u'$

$E=h(N_u\|h(N_s))$

$Sk=h(N_u\|N_s\|u)$

**4.**

$\xleftarrow{C,\ D,\ E}$

**5**.

**Computes**

$N_s'=C\oplus h(N_u)$

**Checks**

$E\ ?=\ h(N_u\|h(N_s'))$, if so

/***For next login**, **the smart card updates** $A$, $C_v$ */

$A=D\oplus N_s'\oplus h(B)\oplus N_u$

$C_v=N_s'\oplus h(B)\oplus h(N_u)$

$Sk=h(N_u\|N_s'\|u)$

**Fig. 2. login and authentication phase**

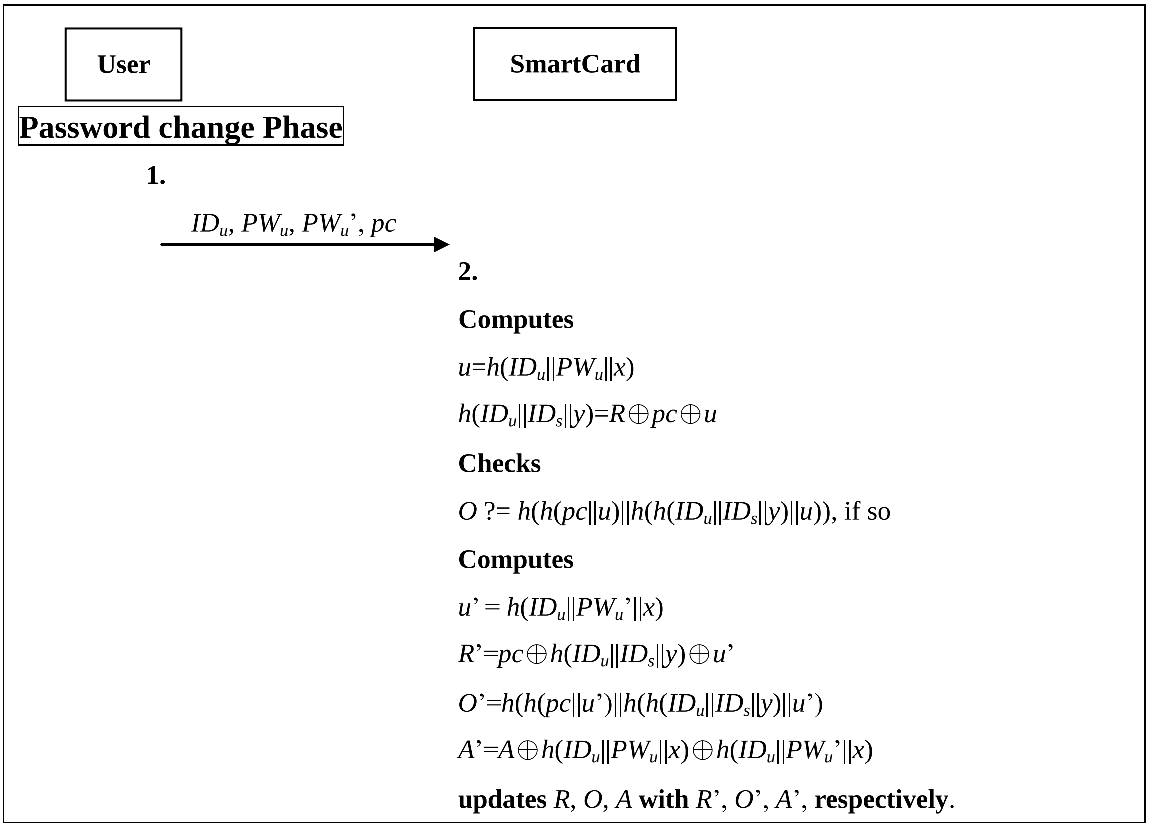
### 3.3 Password Change Phase

When U wants to change his password from $PW_u$ to $PW_u'$, he performs the following steps.

Step 1. U inserts his smart card, and inputs his $ID_u$, $PW_u$, the new password $PW_u'$, and $pc$.

Step 2. The smart card computes $u=h(ID_u||PW_u||x)$, $h(ID_u||ID_s||y)=R\oplus pc\oplus u$, and checks to see whether $O=h(h(pc||u)||h(h(ID_u||ID_s||y)||u))$ holds. If it holds, the smart card computes $u'=h(ID_u||PW_u'||x)$, $R'=pc\oplus h(ID_u||ID_s||y)\oplus u'$, $O'=h(h(pc||u')||h(h(ID_u||ID_s||y)||u'))$, and $A'=A\oplus h(ID_u||PW_u||x)\oplus h(ID_u||PW_u'||x)$, and then updates $R$, $O$, $A$ with $R'$, $O'$, $A'$, respectively.

The flow chart of the Password Change Phase is shown in Fig. 3.



**User**

**SmartCard**

**Password change Phase**

**1.**

$ID_u$, $PW_u$, $PW_u'$, $pc$ →

**2.**

**Computes**

$u=h(ID_u||PW_u||x)$

$h(ID_u||ID_s||y)=R\oplus pc\oplus u$

**Checks**

$O$ ?= $h(h(pc||u)||h(h(ID_u||ID_s||y)||u))$, if so

**Computes**

$u' = h(ID_u||PW_u'||x)$

$R'=pc\oplus h(ID_u||ID_s||y)\oplus u'$

$O'=h(h(pc||u')||h(h(ID_u||ID_s||y)||u'))$

$A'=A\oplus h(ID_u||PW_u||x)\oplus h(ID_u||PW_u'||x)$

**updates** $R$, $O$, $A$ **with** $R'$, $O'$, $A'$, **respectively**.

**Fig. 3. Password change Phase**

## 4. Security analyses

In this section, we demonstrate why our scheme can meet Liao *et al.*’s ten requirements [9] for a smart-card based password authentication protocol.

- **Satisfying the ten security requirements (R1 through R10)**

**R1. It requires no password or verifier tables.**

Our scheme requires no verifier tables stored in the server's memory. Therefore, it meets this requirement.

**R2. The user can choose and change his/her password at will.**

Since in our scheme, the password change request can be accepted only after the smart card has successfully authenticated the user. This guarantees that only the real card holder can securely and freely change his password. In other words, our password change protocol can let the user choose and change his password freely and securely.

**R3. The user needs not reveal his/her password to the administrator of the server.**

Obviously, the password is not revealed to the administrator of the server in either the login and authentication phase, or password change phase of our scheme.

**R4. The password is not transmitted in plain text over the Internet.**

As shown in Section 3, the password in our scheme is not transmitted in clear form. Therefore, our scheme can satisfy this requirement.

**R5. It can resist insider attacks.**

An insider attack means that a legal user J can impersonate another user U to gain the service of server S. Assume that J wants to impersonate U to login to S; however, without the knowledge of U's password $PW_u$ and $u(=h(ID_u||PW_u||x))$, he can not deduce $A$, $M$, $Q$ to pass S's verification.

**R6. It can resist the replay, password guessing, modification-verifier-table, and stolen-verifier attacks.**

Our scheme can resist the modification-verifier-table attack and stolen-verifier attack because it requires no verifier table. In addition, our scheme can avoid the replay attack, because it chooses two fresh nonces, $N_u$ and $N_s$, for each protocol run. In addition, the on-line password guessing attack will fail. Because without the values $ID_u$, $PW_u$, $y$, and $x$, the attacker cannot compute $B$ and $u$ for generating the required parameters $A$, $F$, $M$, $N$, and $Q$ to pass S's examinations.

**R7. The length of a password is appropriate for memorization.**

In our scheme, $PW_u$ is included in $u(=h(ID_u \parallel PW_u \parallel x))$, and then used to generate parameters $A$, $F$, $M$, $N$, and $Q$ in the message flow. Hence our scheme's strength didn't rely on the length of the password. The user therefore can choose any length of password for easy memorization.

**R8. It is efficient and practical.**

Our scheme had another advantage that it demands only two passes and requires no complex computation. It only makes the usage of hash functions and X-or operations. Therefore, our scheme was efficient and practical.

**R9. It achieves mutual authentication.**

Mutual authentication [14] means both the server and the user can authenticate each other before generating the common session key. In the following, we first demonstrate why our protocol can achieve this goal. Then, show why our scheme can resist against Man-In-the-Middle Attack (MIMA).

(a) Mutual authentication :

In the login and authentication phase, to authenticate U**,** S has to verify the validity of $Q$ and $M$, and U must check the validity of $E=h(N_u||h(N_s'))$ to authenticate S. In other words, when both parties complete the corresponding parameters' validity checking, they successfully authenticate each other.

(b) Man-In-the-Middle attack :

Man-in-the-middle attack means that an active attacker might intercept the communication line between a legal user and the server and uses some means to successfully masquerade as both the server to the user, and the user to the server. Then, the user will believe that he is talking to the intended server and vice versa.

We now illustrate such a MIMA launching on our protocol in Fig. 4. In the figure, after having intercepted the communication line between S and U, the attacker AE impersonates U by sending $\{ C_v', A', F', M', N', Q', T'\}$ to S and masquerades as S by sending $\{C', D', E'\}$ to U. If S can successfully verify $Q'$, $M'$, and U can successfully confirm $E'$, AE then is regarded as authentic by both of the two communicating parties and will have the two common session keys shared with U and S, respectively. However, since that for verifying $Q'$ and $M'$, S should compute $Q'=h(u'||h(N_u'||u'))$, and $M'=h(T||u||h(B'||N))$, where $u'=A \oplus B'$, $B'=h(ID_s||y||C_v)$, without the knowledge of $N_u$, $u$, and $y$, AE can't send valid $Q'$ and $M'$. Similarly, for verifying $E'$, User should compute $E=h(N_u||h(N_s'))$, where $N_s'=C \oplus h(N_u)$. However, without the knowledge of $N_u$ and $N_s$, AE can't send valid $E'$. Hence, the MIMA fails.

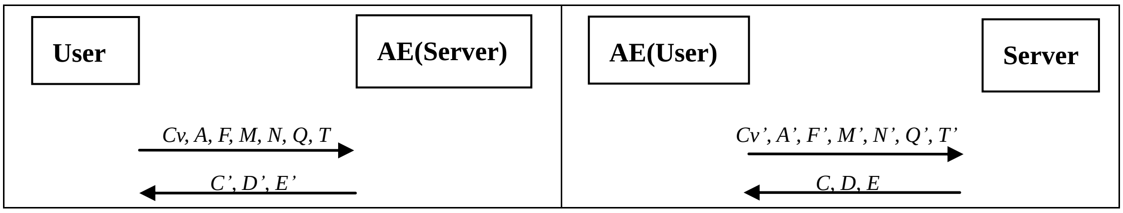


**Fig. 4. The MIMA on our scheme as shown in Fig. 1**

### R10. It resists password guessing attacks, even if the smart card is lost.

The smart-card-loss attack means an attacker AE can launch various attacks when he obtains a legal user's smart card [23]. In the following, under such a situation we discuss the most common attack, the off-line password guessing attack, to demonstrate why our scheme is free from such an attack.

Suppose U's smart card is obtained by AE after registration. Though, AE can read the stored values {$h(\cdot)$, $ID_u$, $C_v$, $A(=B\oplus u(=h(ID_s||y||C_v))\oplus h(ID_s||y))\oplus h(ID_u||PW_u||x))$, $x$}. However, without the knowledge of $u = h(ID_u \parallel PW_u \parallel x)$, AE cannot confirm whether his password guessing is right. Therefore, he cannot launch off-line password guessing attack; for example, AE may guess password $PW_u$ as $PW_{AE}$ and compute $h(ID_u||PW_{AE}||x)$; however, without the knowledge of value $u$, AE cannot confirm the validity of his guessing. In the other case, suppose U's smart card is obtained by AE after the login and authentication phase, since even in the former case AE can not obtain any reduction in advantage. Not to mention, $C_v$ and $A$ are further randomized in this case. From the above description, we therefore conclude that AE can not launch such an attack.

## 5. Comparisons and Applications

- **Comparisons**

After having examined the ten security requirements, in the following, we make comparisons, among our scheme and other existing 2PAKE protocols [1, 3-6, 9, 11, 17, 21, 22, 26, 27, 29, 30-33, 35] in passes needed and whether it can satisfy the ten security features (STSF) proposed by Liao et al. We show the results in Table 1. For convenience, in the table, we use notations i(1)-[35] to denote the first improvement in [35].

**Table 1. Comparisons with some smart-card password based schemes in the passes and STSF**

| Schemes | i(1)-[35] | [1] | [3] | [4] | [5] | [6] | [9] | [11] | [17] | [21] | [22] |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Passes | 2 | 2 | 2 | 2 | 3 | 4 | 3 | 3 | 2 | 2 | 3 |
| Anonymity | × | × | × | × | × | ○ | × | × | ○ | × | ○ |
| STSF | ○ | × | ○ | ○ | ○ | × | × | × | × | × | × |

**Table 1- continued. Comparisons with some smart-card password based schemes in the passes and STSF**

| Schemes | [26] | [27] | [29] | [30] | [31] | [32] | [33] | [37] | [39] | Ours |
|---|---|---|---|---|---|---|---|---|---|---|
| Passes | 2 | 2 | 3 | 2 | 4 | 4 | 3 | 2 | 2 | 2 |
| Anonymity | × | × | × | × | ○ | × | × | × | ○ | ○ |
| STSF | × | × | × | × | × | ○ | ○ | × | ○ | ○ |

From Table 1, we concluded that our scheme outperforms the others, except [39] which is the same as ours, in three dimensions: passes, anonymity, and STSF. However, [39] uses of RSA public key encryption which is computationally intensive. Moreover, it also has a fixed parameter $C_1$ in each login of the user which makes their scheme traceable.

- **Application**

- Smart Grid

Based on our two-pass one-to-one (server-user) authentication protocol, **(**which not only can meet Liao *et al.'*s ten requirements, but also is more secure and efficient than other relevant works in the literature), our future work will adapt and apply it to a smart grid network. The smart grid network operates under the circumstance that contains multiple users (customers), electrical equipment, and one operation center. It is prone to suffering security vulnerabilities and requires much computational overhead [36]. Our work requires only hash and x-or operations. Therefore, it is more suitable to be adapted and applied in a smart grid network or future mobile communication networks, which may contain more servers to cope with multiple users, than the others.

## 6. Conclusion

This paper showed the weakness of Khan et al.'s authentication protocol in Section 2, then demonstrates why our scheme satisfies the ten security requirements for remote user authentications indicated by Liao et al., and why it can prevent the insider attack and password guessing attack when the smart card is lost. Finally, it compares with the other proposed works in the literature for three factors: (1) required number of passes, (2) ten security features, and (3) anonymity property. From Table 1, we concluded that our scheme outperformed the others. The only concern for our scheme was the DOS attack. However, our scheme used only the hash and Xor operations which are very efficient. To counter the attack, we can further tune the number of login users to some amount. Therefore, it was more suitable to be applied in real applications, such as smart grid or future mobile communication networks, than the others.

## References

[1] Muhammad Khurram Khan, soo-Kyun Kim, Khaled Alghathbar, "Cryptanalysis and security enhancement of a 'more efficient & secure dynamic ID-based remote user authentication scheme'", Journal of Computer Communications, Vol. 6, No. 4, pp. 305-309, 2011.

[2] Daojing He, Maode Ma, Yan Zhang, Chun Chen, Jiajun Bu, "A Strong user authentication scheme with smart card for wireless communications", Journal of Computer Communications, Vol. 34, No. 3, pp. 367-374, 2011.

[3] Ronggong Song, "Advanced smart card based password authentication protocol", Journal of Computer Standards & Interfaces, Vol. 32, No. 5-6, pp. 321-325, 2010.

[4] Xiong Li, Jian-Wei Niu, Jian Ma, Wen-Dong Wang, Cheng-Lian Liu, "Cryptanalysis and improvement of a biometrics-based remote user authentication scheme using

smart cards", Journal of Network and Computer Applications, Vol. 34, No. 1, pp. 73-79, 2011.

[5] Amit K. Awasthi, Keerti Srivastava, R.C. Mittal, "An improved timestamp-based remote user authentication scheme", Journal of Computers and Electrical Engineering, Vol. 37, No. 6, pp. 869-874, 2011.

[6] SK. Hafizul Islam, G.p. Biswas, "A more efficient for secure ID- based remote mutual authentication with key agreement scheme for mobile devices on elliptic curve cryptosystem", Journal of Systems and Software, Vol. 84, No. 11, pp. 1892-1898, 2011.

[7] Sandeep K. Sood, Anil K. Sarje, Kuldip Singh, "A secure dynamic identity based authentication protocol for multi-server architecture", Journal of Network and Computer Applications, Vol. 34, No. 2, pp. 609-618, 2011.

[8] Hui Li, Chuan-Kun Wu, Jun Sun, "A general compiler for password- authentication group key exchange protocol", Journal of Information Processing Letters, Vol. 110, No. 4, pp. 160-167, 2010

[9] I-En Liao, Cheng-Chi Lee, Min-Shiang Hwang, "A password authentication scheme over insecure networks", Journal of Computer and System Sciences, Vol. 72, No. 4, pp. 727-740, 2006.

[10] J-Han Yang, Tian-Jie Cao, "Provably secure three-party password authenticated key exchange protocol in the standard model", The Journal of Systems and Software, Vol. 85, No. 2, pp. 340-350, 2012.

[11] Ren-Chiun Wang, Wen-Sheng Juang, Chin-Laung Lei, "Robust authentication and key agreement scheme preserving the privacy of secret key", Journal of Computer Communications, Vol. 34, No. 3, pp. 274-280, 2011.

[12] Junghyun Nam, Juryon Paik, Dongho Won, "A security weakness in Abdalla et al.'s generic construction of a group key exchange protocol", Journal of Information Science, Vol. 181, No. 1, pp. 234-238, 2011.

[13] Ting-Yi Chang, Min-Shiang Hwang, Wei-Pang Yang, "A communication- efficient three-party password authenticated key exchange protocol", Journal of Information Sciences, Vol. 181, No. 1, pp. 217-226, 2011.

[14] Yunho Lee, Seungjoo Kim, Domgho Won, "Enhancement of two- factor authemticated key exchange protocols in public wireless LANs", Journal of Computers and Electrical Engineering, Vol. 36, No. 31, pp. 213-223, 2010.

[15] Binod Vaidya, Jong Hyuk Parkm, Sang-Soo Yeo, Joel J.P.C. Rodrigues, "Robust one-time password authentication scheme using smart card for home network environment", Journal of Computer Communications, Vol. 34, No. 3, pp. 326-336, 2011.

[16] Qiang Tang, Liqun Chen, "Extended KCI attack against two-party key establishment protocols", Joutnal of Information Processing Letters, Vol. 111, No.

15, pp. 744-747, 2011.

[17] Kuo-Hui Yeh, Chunhua Su, N.W. Lo, Yingjiu Li, Yi-Xiang Hung, “Two robust remote user authentication protocols using smart cards”, The Journal of Systems and Software, Vol. 83, No. 12, pp. 2556-2565, 2010

[18] Jonathan Katz, Philip Mackenzie, Gelareh Taban, Virgil Gligor, “Two-server password-only authenticated key exchange”, Journal of Computer and System Sciences, Vol. 78, No. 2, pp. 651-669, 2012.

[19] SK Hafizul Islam, G.P. Biswas, “Design of improved password authentication and update scheme based on elliptic curve cryptography”, Journal of Mathematical and Computer Modelling, 2010.

[20] Yi-Pin Liao, Shuenn-Shyang Wang, “A new secure password authenticated key agreement scheme for SIP using self-certified public keys on elliptic curves”, Journal of Computer Communications, Vol. 33, No. 3, pp. 372-380, 2010.

[21] Tien-Ho Chen, Han-Cheng Hsiang, Wei-Kuan Shih, “Security enhancement on an improvement on two remote user authentication scheme using smart cards”, Journal of Future Generation Computer Systems, Vol. 27, No. 4, pp. 377-380, 2011.

[22] Cheng-Chi Leem Tsung-Hung Lin, Rui-Xiang Chang, “A secure dynamic ID based remote user authentication scheme for multi-server environment using smart cards”, Journal of Expert Systems with Applications, Vol. 38, No. 11, pp. 13863-13870, 2011.

[23] Ren-Chiun Wang, Wen-Shenq Juang, Chin-Laung Lei, “Provably secure and efficient identification and key agreement protocol with user anonymity”, Journal of Computer and System Sciences, Vol. 77, No. 4, pp. 790-798, 2011.

[24] Tian-Fu Lee, Tzonelih Hwang, “Simple password-based three-party authenticated key exchange without server public keys”, Journal of Information Sciences, Vol. 180, No. 9, pp. 1702-1714, 2010.

[25] A.M. Rossudowski, H.S. Venter, J.H.P. Eloff, D.G. Kourie, “A security privacy aware architecture and protocol for a single smart card used for multiple services”, ScienceDirect Computers & Security, Vol. 29, No. 4, pp. 393-409, 2010.

[26] Sang-Kyun Kim, Min Gyo Chung, “More secure remote user authentication scheme”, Computer Communications, Vol. 32, No. 6, pp. 1018-1021, 2009.

[27] Yan-yan Wang, Jia-yong Liu, Feng-xia Xiao, Jing Dan, “A more efficient and secure dynamic ID-based remote user authentication scheme”, Computer Communications, Vol. 32, No. 4, pp. 583-585, March 2009.

[28] Xiong Li, Yongping Xiong, Jian Ma, Wendong Wang, “An efficient and security dynamic identity based authentication protocol for multi-server architecture using smart cards”, Journal of Network and Computer Applications, Vol. 35, No. 2, pp. 763-769, 2012.

[29] Chun-TaLi, Min-ShiangHwang, “An efficient biometrics-based remote user authentication scheme using smart cards”, Journal of Network and Computer Applications, Vol. 33, No. 1, pp. 1-5, 2010.

[30] Han-Cheng Hsiang, Wei-Kuan Shih, “Weaknesses and improvements of the Yoon–Ryu–Yoo remote user authentication scheme using smart cards”, Computer Communications, Vol. 32, No. 4, pp. 649-652, 2009.

[31] Chun-Ta Li, Cheng-Chi Lee, “A novel user authentication and privacy preserving scheme with smart cards for wireless communications”, Mathematical and Computer Modeling, Vol. 55, No. 1-2, pp. 35-44, 2012.

[32] Min-Shiang Hwang, Song-Kong Chong, Te-Yu Chen, “DoS-resistant ID-based password authentication scheme using smart cards”, Journal of Systems and Software, Vol. 83, No. 1, pp. 163-172, 2010.

[33] Hao-Rung Chung, Wei-Chi Ku, Maw-Jinn Tsaur, “Weaknesses and improvement of Wang et al.'s remote user password authentication scheme for resource-limited environments”, Computer Standards & Interfaces, Vol. 31, No. 4, pp. 863-868, 2009.

[34] R. Madhusudhan, R.C. Mittal, “Dynamic ID-based remote user password authentication schemes using smart cards: A review”, Journal of Networks and Computer Applications, Vol. 35, No. 4, pp. 1235-1248, 2012.

[35] Yalin Chen, Jue-Sam Chou, Chun-Hui Huang, “Improvements on two password-based authentication protocols”, http://eprint.iacr.org/2009/561 Cryptology ePrint Archive.

[36] R Lu, X Liang, X Li, X Lin, X Shen, “EPPA: An Efficient and Privacy-Preserving Aggregation Scheme for Secure Smart Grid Communications”, *IEEE Transactions On Parallel And Distributed Systems*, Vol. 23, No. 9, 2012.

[37] R. Song, “Advanced smart card based password authentication protocol”, *Computer Standards & Interfaces*, Vol. 32, No. 5-6, 2010.

[38] Tsu-Yang Wu, Yuh-Min Tseng, “An efficient user authentication and key exchange protocol for mobile client – server environment”, *Computer Networks*, Vol. 54, No. 9, pp. 1520-1530, 2010.

[39] W. Ding and C.G. Ma,” Cryptanalysis and security enhancement of a remote user authentication scheme using smart cards”, *The Journal of China Universities of Posts and Telecommunications*, Volume 19, Issue 5, October 2012, Pages 104 – 114

[40] L. Gong, J. Pan, B. Liu, S. Zhao, “A novel one-time password mutual authentication scheme on sharing renewed finite random sub-passwords”, *Journal of Computer and System Sciences*, Vol. 79 Issue 1, Pages 122-130, February, 2013.

[41] D. He, S., Wu , and J. Chen, ”note on 'design of improved password authentication and update scheme based on elliptic curve cryptography”, *Mathematical and*

*Computer Modelling*, Vol. 55(3–4), Pages 1661– 1664

[42] S. H. Islam and G.P. Biswas, “Design of improved password authentication and update scheme based on elliptic curve cryptography”, *Mathematical and Computer Modelling*, Volume 57, Issues 11 – 12, June 2013, Pages 2703 – 2717

[43] X. Li, J. Niu, M. Khurram Khan, J. Liao, “An enhanced smart card based remote user password authentication scheme ”, *Journal of Network and Computer*, Available online 5 March 2013

[44] Q. Xie,”Improvement of a security enhanced one-time two-factor authentication and key agreement scheme”, *Scientia Iranica*, Vol. 19, Issue 6, December 2012, Pages 1856 – 1860