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Cryptanalysis of a certificateless aggregate signature scheme for mobile computation

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Abstract: Recently, Xiong et al. proposed an efficient certificateless aggregate signature (CLAS) scheme for mobile computation. They demonstrated that their scheme is provably secure in the random oracle model. Unfortunately, by giving a concrete attack, in this paper, we point out that Xiong et al.'s scheme is not secure at all and an adversary without the partial private key and the secret value could forge a legal message. Hence, Xiong et al.'s scheme is not feasible for practical applications.

Keywords: Certificateless cryptography; Aggregate signature; Bilinear pairing

1 Introduction

The aggregate signature (AS) scheme, which was first introduced by Boneh et al. [1], is a variation of the signature scheme. The AS scheme could aggregate n signatures on n distinct messages from n distinct users into a single signature. The AS scheme has been wide used in practical applications since it could reduce bandwidth and storage.

To solve the key escrow problem in the ID-based public key cryptography, Al-Riyami et al. [2] proposed the concept of the certificateless public key cryptography. Since then, many certificateless signature schemes [3,4,5], certificateless key agreement schemes [6,7,8] and certificateless signcryption schemes [9,10] have been proposed. To satisfy applications in certificateless environment, several certificateless aggregate signature (CLAS) schemes [11,12,13,14] also were proposed. Recently, Xiong et al. [15] proposed a new CLAS scheme using bilinear pairings. Compared with previous CLAS schemes [11,12,13,14], Xiong et al.'s scheme is very efficient in terms of computation. They also demonstrated that their scheme is provably secure in the random oracle model. Unfortunately, we find that a general adversary, who knows nothing about the partial private key and the secret value, could forge a legal signature of any message. The analysis shows Xiong et al.'s schemes are not secure for practical applications.

The organization of the paper is sketched as follows. Section 2 gives a brief review of Xiong et al.'s scheme. The security flaw of Xiong et al.'s scheme is shown in Section 3. Finally, we give some conclusions in Section 4.

2 Review of Xiong et al.'s schemes

In this section, we will briefly review Xiong et al.'s CLAS scheme. Their CLAS scheme consists of six algorithms: *MasterKeyGen*, *PartialKeyGen*, *UserKeyGen*, *Sign*, *Aggregate* and *AggregateVerify*. The detail of these algorithms is described as follows:

MasteKeyGen : Given a security parameter , the key generation centre(KGC) runs the algorithm as follows:

–1 Generate a cyclic additive group G_1 and a cyclic multiplicative group G_2 with prime order q.

–2 Generate two generators P, Q of G_1 and an admissible pairing $e : G_1 \times G_1 \rightarrow G_2$.

–3 Generate a random number $s \in Z_q^*$ and compute $P_{pub} = sP$.

–4 Choose cryptographic hash functions $H_0, H_0^{'} : \{0,1\}^* \rightarrow G_1$ and $H_1, H_2, H_2^{'} \{0,1\}^* \rightarrow Z_q$.

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–5 KGC publishes the system parameters, which are $\left\{q, G_1, G_2, e, P, Q, P_{pub}, H_0, H_0^{'}, H_1, H_2, H_2^{'}\right\}$ and key the master key s secretly.

PartialKeyGen: Given a user's identity ID_i, KGC computes the user's partial private key $psk_{ID_i} = \left(sQ_{ID_i}, sQ_{ID_i}^{'}\right)$ and transmits it to the user secretly, where $Q_{ID_i} = H_0\left(ID_i\right)$ and $Q_{ID_i} = H_0^{'}\left(ID_i\right)$.

UserKeyGen: The user with identity ID_i selects a random number $x_{ID_i} \in Z_q^*$ as his secret key usk_{ID_i}, and computes his public key as $upk_{ID_i} = usk_{ID_i}$.

Sign: Given a message m_i, the partial private key psk_{ID_i}, the secret key usk_{ID_i}, the user with identity ID_i and the corresponding public key upk_{ID_i} performs the following steps to generate a signature.

1) Compute
$h_{i1} = H_1\left(m_i, ID_i, upk_{ID_i}\right)$,
$h_{i2} = H_2\left(m_i, ID_i, upk_{ID_i}\right)$ and
$h_{i2}^{'} = H_2^{'}\left(m_i, ID_i, upk_{ID_i}\right)$.

2) Compute
$\sigma_i = h_{i1} \cdot uskr_{ID_i} \cdot Q + h_{i2} \cdot sQ_{ID_i} + h_{i2}^{'} \cdot sQ_{ID_i}^{'}$.

3) Output σ_i as the signature on m_i.

Aggregate: For an aggregating set of n users $\{u_1, \ldots, u_n\}$ with identities $\{ID_1, \ldots, ID_n\}$ and the corresponding public keys $\{upk_1, \ldots, upk_n\}$, and message-signature pairs $\{(m_1, \sigma_1), \ldots, (m_n, \sigma_n)\}$ from $\{u_1, \ldots, u_n\}$ respectively, the aggregate signature generator computes $\sigma = \sum_{i=1}^{n} \sigma_i$ and outputs σ as an aggregate signature.

AggregateVerify: To verify an aggregate signature σ signed by n users $\{u_1, \ldots, u_n\}$ with identities $\{ID_1, \ldots, ID_n\}$ and the corresponding public keys $\{upk_1, \ldots, upk_n\}$ on messages $\{m_1, \ldots, m_n\}$, the verifier performs the following steps:

1) Compute
$Q_{ID_i} = H_0\left(ID_i\right)$,
$Q_{ID_i}^{'} = H_0^{'}\left(ID_i\right)$,
$h_{i1} = H_1\left(m_i, ID_i, upk_{ID_i}\right)$,
$h_{i2} = H_2\left(m_i, ID_i, upk_{ID_i}\right)$ and
$h_{i2}^{'} = H_2^{'}\left(m_i, ID_i, upk_{ID_i}\right)$ for $i = 1, \ldots, n$.

2) Verify

$$e\left(\sigma, P\right) = e\left(\sum_{i=1}^{n} h_{i1} \cdot upk_{ID_i}, Q\right) \times e\left(\sum_{i=1}^{n} \left(h_{i2} \cdot Q_{ID_i} + h_{i2}^{'} \cdot Q_{ID_i}^{'}\right), P_{pub}\right)$$

holds or not. If it holds, accept the signature.

3 Cryptanalysis of Xiong et al.'s scheme

Xiong et al. [15] claimed their CLAS scheme is provably secure under the assumption of computational Diffie-Hellman problem [16, 17]. Unfortunately, it is not true, since an adversary A could extract the partial private key and the secret value from the intercepted signatures. Therefore, A could forge a signature of any message using the two private keys. The detail of the attack is described as follows:

Step 1:

For $i = 1, 2, \ldots, n$, A gets $uskr_{ID_i} \cdot Q$, sQ_{ID_i} and $sQ_{ID_i}^{'}$ through the following steps:

A submits ID_i and three messages $m_i, \overline{m}_i$ and $\overline{\overline{m}}_i$ to the *Sign* oracle and gets three legal signatures $\sigma_i, \overline{\sigma}_i$*and* $, \overline{\overline{\sigma}}_i$ of message $m_i, \overline{m}_i$ and $\overline{\overline{m}}_i$ respectively, where

$\sigma_i = h_{i1} \cdot uskr_{ID_i} \cdot Q + h_{i2} \cdot sQ_{ID_i} + h_{i2}^{'} \cdot sQ_{ID_i}^{'}$,

$\overline{\sigma}_i = \overline{h}_{i1} \cdot usk_{ID_i} \cdot Q + \overline{h}_{i2} \cdot sQ_{ID_i} + \overline{h}_{i2}^{'} \cdot sQ_{ID_i}^{'}$,

$\overline{\overline{\sigma}}_i = \overline{\overline{h}}_{i1} \cdot uskr_{ID_i} \cdot Q + \overline{\overline{h}}_{i2} \cdot sQ_{ID_i} + \overline{\overline{h}}_{i2}^{'} \cdot sQ_{ID_i}^{'}$,

$h_{i1} = H_1\left(m_i, ID_i, upk_{ID_i}\right)$,
$h_{i2} = H_2\left(m_i, ID_i, upk_{ID_i}\right)$,
$h_{i2}^{'} = H_2^{'}\left(m_i, ID_i, upk_{ID_i}\right)$,
$\overline{h}_{i1} = H_1\left(\overline{m}_i, ID_i, upk_{ID_i}\right)$,
$\overline{h}_{i2} = H_2\left(\overline{m}_i, ID_i, upk_{ID_i}\right)$,
$\overline{h}_{i2} = H_2^{'}\left(\overline{m}_i, ID_i, upk_{ID_i}\right)$,
$\overline{\overline{h}}_{i1} = H_1\left(\overline{\overline{m}}_i, ID_i, upk_{ID_i}\right)$,
$\overline{\overline{h}}_{i2} = H_2\left(\overline{\overline{m}}_i, ID_i, upk_{ID_i}\right)$
and
$\overline{\overline{h}}_{i2} = H_2^{'}\left(\overline{\overline{m}}_i, ID_i, upk_{ID_i}\right)$.

Then, we could get the following three equations.

$$\sigma_i = h_{i1} \cdot uskr_{ID_i} \cdot Q + h_{i2} \cdot sQ_{ID_i} + h_{i2}^{'} \cdot sQ_{ID_i}^{'} \tag{1}$$

$$\overline{\sigma}_i = \overline{h}_{i1} \cdot usk_{ID_i} \cdot Q + \overline{h}_{i2} \cdot sQ_{ID_i} + \overline{h}_{i2}^{'} \cdot sQ_{ID_i}^{'} \tag{2}$$

and

$$\overline{\overline{\sigma}}_i = \overline{\overline{h}}_{i1} \cdot uskr_{ID_i} \cdot Q + \overline{\overline{h}}_{i2} \cdot sQ_{ID_i} + \overline{\overline{h}}_{i2}^{'} \cdot sQ_{ID_i}^{'} \tag{3}$$

The probability of $\begin{vmatrix} h_{i1} & h_{i2} & h_{i2}^{'} \\ \overline{h}_{i1} & \overline{h}_{i2} & \overline{h}_{i2}^{'} \\ \overline{\overline{h}}_{i1} & \overline{\overline{h}}_{i2} & \overline{\overline{h}}_{i2}^{'} \end{vmatrix} = 0$ is negligible since all the elements of the determinant are random number. So we could get the values of $uskr_{ID_i} \cdot Q, sQ_{ID_i}$ and $sQ_{ID_i}^{'}$ as follows.

$$sQ_{ID_i} = \begin{vmatrix} h_{i1} & \sigma_i & h_{i2}^{'} \\ \overline{h}_{i1} & \overline{\sigma}_i & \overline{h}_{i2}^{'} \\ \overline{\overline{h}}_{i1} & \overline{\overline{\sigma}}_i & \overline{\overline{h}}_{i2}^{'} \end{vmatrix} \Big/ \begin{vmatrix} h_{i1} & h_{i2} & h_{i2}^{'} \\ \overline{h}_{i1} & \overline{h}_{i2} & \overline{h}_{i2}^{'} \\ \overline{\overline{h}}_{i1} & \overline{\overline{h}}_{i2} & \overline{\overline{h}}_{i2}^{'} \end{vmatrix} \tag{4}$$

$$uskr_{ID_i}\cdot Q=\begin{vmatrix}\sigma_i & h_{i2} & h_{i2}^{'}\\ \bar{\sigma}_i & \bar{h}_{i2} & \bar{h}_{i2}^{'}\\ \bar{\bar{\sigma}}_i & \bar{\bar{h}}_{i2} & \bar{\bar{h}}_{i2}^{'}\end{vmatrix}\Big/\begin{vmatrix}h_{i1} & h_{i2} & h_{i2}^{'}\\ \bar{h}_{i1} & \bar{h}_{i2} & \bar{h}_{i2}^{'}\\ \bar{\bar{h}}_{i1} & \bar{\bar{h}}_{i2} & \bar{\bar{h}}_{i2}^{'}\end{vmatrix} \tag{5}$$

$$=\frac{\bar{h}_{i2}\bar{\bar{h}}_{i2}^{'}\cdot\sigma_i+\bar{\bar{h}}_{i2}h_{i2}^{'}\cdot\bar{\sigma}_i+h_{i2}^{'}\bar{h}_{i2}^{'}\cdot\sigma_i-h_{i2}^{'}\bar{\bar{h}}_{i1}\cdot\bar{\bar{\sigma}}_i-h_{i2}^{'}\bar{h}_{i2}\cdot\bar{\bar{\sigma}}_i-h_{i2}\bar{\bar{h}}_{i2}^{'}\cdot\bar{\sigma}_i}{h_{i1}\bar{h}_{i2}\bar{\bar{h}}_{i2}^{'}+\bar{h}_{i1}\bar{\bar{h}}_{i2}h_{i2}^{'}+h_{i2}\bar{h}_{i2}^{'}\bar{\bar{h}}_{i1}-h_{i2}^{'}\bar{h}_{i2}\bar{\bar{h}}_{i1}-\bar{h}_{i2}^{'}\bar{\bar{h}}_{i2}h_{i1}-h_{i2}\bar{h}_{i1}\bar{\bar{h}}_{i2}^{'}}$$

$$=\frac{h_{i1}\bar{\bar{h}}_{i2}^{'}\cdot\bar{\sigma}_i+\bar{h}_{i1}h_{i2}^{'}\cdot\bar{\bar{\sigma}}_i+\bar{h}_{i2}^{'}\bar{\bar{h}}_{i1}\cdot\sigma_i-h_{i2}^{'}\bar{\bar{h}}_{i1}\cdot\bar{\sigma}_i-\bar{h}_{i2}h_{i1}\cdot\bar{\bar{\sigma}}_i-\bar{h}_{i1}\bar{\bar{h}}_{i2}^{'}\cdot\sigma_i}{h_{i1}\bar{h}_{i2}\bar{\bar{h}}_{i2}^{'}+\bar{h}_{i1}\bar{\bar{h}}_{i2}h_{i2}^{'}+h_{i2}\bar{h}_{i2}^{'}\bar{\bar{h}}_{i1}-h_{i2}^{'}\bar{h}_{i2}\bar{\bar{h}}_{i1}-\bar{h}_{i2}^{'}\bar{\bar{h}}_{i2}h_{i1}-h_{i2}\bar{h}_{i1}\bar{\bar{h}}_{i2}^{'}}$$

and

$$sQ_{ID_i}^{'}=\begin{vmatrix}h_{i1} & h_{i2} & \sigma_i\\ \bar{h}_{i1} & \bar{h}_{i2} & \bar{\sigma}_i\\ \bar{\bar{h}}_{i1} & \bar{\bar{h}}_{i2} & \bar{\bar{\sigma}}_i\end{vmatrix}\Big/\begin{vmatrix}h_{i1} & h_{i2} & h_{i2}^{'}\\ \bar{h}_{i1} & \bar{h}_{i2} & \bar{h}_{i2}^{'}\\ \bar{\bar{h}}_{i1} & \bar{\bar{h}}_{i2} & \bar{\bar{h}}_{i2}^{'}\end{vmatrix} \tag{6}$$

$$=\frac{h_{i1}\bar{h}_{i2}\cdot\bar{\bar{\sigma}}_i+\bar{h}_{i1}\bar{\bar{h}}_{i2}\cdot\sigma_i+h_{i2}\bar{\bar{h}}_{i1}\cdot\bar{\sigma}_i-\bar{h}_{i2}\bar{\bar{h}}_{i1}\cdot\sigma_i-\bar{\bar{h}}_{i2}h_{i1}\cdot\bar{\sigma}_i-h_{i2}\bar{h}_{i1}\cdot\bar{\bar{\sigma}}_i}{h_{i1}\bar{h}_{i2}\bar{\bar{h}}_{i2}^{'}+\bar{h}_{i1}\bar{\bar{h}}_{i2}h_{i2}^{'}+h_{i2}\bar{h}_{i2}^{'}\bar{\bar{h}}_{i1}-h_{i2}^{'}\bar{h}_{i2}\bar{\bar{h}}_{i1}-\bar{h}_{i2}^{'}\bar{\bar{h}}_{i2}h_{i1}-h_{i2}\bar{h}_{i1}\bar{\bar{h}}_{i2}^{'}}$$

Step 2 :
For $i=1,2,...,n$ and a given message m_i, A computes
$\widetilde{h}_{i1}=H_1(m_i,ID_i,upk_{ID_i})$,
$\widetilde{h}_{i2}=H_2(m_i,ID_i,upk_{ID_i})$,
$\widetilde{h}_{i2}^{'}=H_2^{'}(m_i,ID_i,upk_{ID_i})$, and
$\sigma_i=\widetilde{h}_{i1}\cdot uskr_{ID_i}\cdot Q+\widetilde{h}_{i2}\cdot sQ_{ID_i}+\widetilde{h}_{i2}^{'}\cdot sQ_{ID_i}^{'}$,
where $uskr_{ID_i}\cdot Q, sQ_{ID_i}$ and $sQ_{ID_i}^{'}$ are the values computed in the above step.

Step 3 : A computes
$\sigma=\sum\limits_{i=1}^{n}\sigma_i$ and outputs σ as the aggregate signature.

Since
$\widetilde{h}_{i1}=H_1(m_i,ID_i,upk_{ID_i})$,
$\widetilde{h}_{i2}=H_2(m_i,ID_i,upk_{ID_i})$,
$\widetilde{h}_{i2}^{'}=H_2^{'}(m_i,ID_i,upk_{ID_i})$
and
$\sigma_i=\widetilde{h}_{i1}\cdot uskr_{ID_i}\cdot Q+$
$\widetilde{h}_{i2}\cdot sQ_{ID_i}+\widetilde{h}_{i2}^{'}\cdot sQ_{ID_i}^{'}$, we could have that

$$\begin{aligned}&e(\widetilde{\sigma},P)=e\left(\sum_{i=1}^{n}\sigma_i,P\right)\\&=e\left(\textstyle\sum_{i=1}^{n}\left(\widetilde{h}_{i1}\cdot usk_{ID_i}\cdot Q+\widetilde{h}_{i2}\cdot sQ_{ID_i}+\widetilde{h}'_{i2}\cdot sQ'_{ID_i}\right),P\right)\\&=e\left(\sum_{i=1}^{n}\widetilde{h}_{i1}\cdot usk_{ID_i}\cdot Q,P\right)e\left(\sum_{i=1}^{n}\left(\widetilde{h}_{i2}\cdot sQ_{ID_i}+\widetilde{h}'_{i2}\cdot sQ'_{ID_i}\right),P\right)\\&=e\left(\sum_{i=1}^{n}\widetilde{h}_{i1}.upk_{ID_i}.Q\right)e\left(\sum_{i=1}^{n}\left(\widetilde{h}_{i2}.Q_{ID_i}+\widetilde{h}'_{i2}\cdot Q'_{ID_i}\right),P_{pub}\right)\end{aligned}\tag{7}$$

Therefore, σ is a legal aggregate signature and Xiong et al.'s CLAS scheme is not secure.

4 Conclusion

In this paper, we show a very efficient CLAS scheme is not secure by proposing a concrete attack. The analysis shows that the scheme is insecure and infeasible for practical applications. We will propose an improved scheme to overcome the security weakness.

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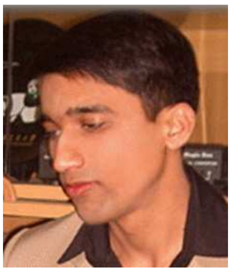

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