An Efficient Biometric Certificateless Signcryption Scheme

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Abstract—Biometric signcryption, which enables a user using his biometric information as the identity to fulfills both the functions of encryption and digital signature simultaneously, and it provides better overall security and performance. However, almost all biometric signcryption schemes that have been proposed in the literature do not satisfy forward secrecy, known session-specific temporary information security and public verifiability with confidentiality, also have the certificate management complexity or key escrow issues which are inherent in traditional public key and identity-based cryptography respectively. In order to solve these problems, a novel biometric signcryption using certificateless public key cryptography is introduced, the formal definition and security notion of the biometric certificateless signcryption (BCSC) are presented, and a concrete BCSC scheme is also proposed in this paper. The proposed scheme eliminates the above security shortcomings and it does not have the certificate management complexity and key escrow issue by exploiting the certificateless public key cryptography. Moreover, the proposed scheme only requires one bilinear pairing operation, which makes it applicable to the resource-constrained communication devices and the communication networks with high security requirements.

Index Terms—cryptography; biometric certificateless signcryption; forward secrecy; random oracle

I. INTRODUCTION

Signcryption is a high performance cryptographic primitive first proposed by Zheng in 1997 as an approach to perform both the functionality of encryption and signature in a single operation, and is more efficient than the sign-then-encrypt approach. In the early decades, many signcryption schemes [1, 2] have been presented using the conventional public key infrastructure (PKI). In PKI, certificate issued by certification authority (CA) is used to bind user’s identity and their public keys. This brings the complex problems associated all users certificate management including certificate generation, distribution, revocation and storage, as well as the communication and computation overheads of certificate verification. To mitigate the burden of conventional PKI, Shamir introduced the notion of Identity-Based Cryptography (IBC). In the IBC system, the user’s public key is replaced by any binary strings that uniquely represent the user and the user’s private key is generated and distributed by a trusted authority called private key generator (PKG), which gets rid of the certificates. The concept of identity-based signcryption (IBSC) was first presented by Malone-Lee in [3]. Subsequently, many IBSC schemes are proposed [4, 5]. However, in IBC all users’ private keys are not selected by the users but rather issued by the PKG, which unfortunately introduces the key distribution and escrow problems, and also has the security risk since the PKG can decrypt and forge any signcryption in an IBSC scheme.

A new cryptographic primitive called certificateless cryptography was introduced by Al-Ryami and Paterson [6] in 2003 in order to address the key distribution and escrow problems while avoiding the use of certificate which are inherent in identity-based and traditional public key cryptography respectively. In the certificateless cryptography system, the user’s private key is divided into two parts. A trusted third party called key generation center (KGC) is also used to generate all users’ private keys, but he only help users generate a partial private key. The other part of private key named secret value is selected by the users themselves and the KGC cannot obtain this secret value. In 2008, Barbosa and Farshim [7] proposed the first certificateless signcryption (CLSC) scheme along with a security model, where the model dealt with security notions of confidentiality and unforgeability for CLSC. Recently, a number of efficient CLSC schemes [8, 9] have been proposed in certificateless cryptography.

Nowadays, many security schemes use the user’s biometric information as his identity instead of arbitrary strings like an IP address since the biometric data is unique and inherent for a user. Some work [10, 11] in applying biometric data to cryptography has focused on the extraction of a secret from biometrics. Sahai and Waters [12] pointed out in above biometric security schemes [10, 11] simply capturing a digital reading of

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Ming Luo is supported by the National Natural Science Foundation of China under grant no. 11226042, the Science and Technology Supporting Program of Jiangxi Province under grant no. 20122BBB50036 and the Science and Technology Project of Jiangxi Provincial Department of Education under grant no. GJJ12147.

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doi:10.4304/jcp.8.7.1853-1860
someone else’s biometric would (forever) invalidate approaches where symmetric keys are systematically derived from biometric readings, and they proposed a new type of identity-based encryption called fuzzy identity-based encryption (Fuzzy-IBE) that uses biometric attributes. But the public parameters grow linearly with the number of attributes in Sahai and Waters’s Fuzzy-IBE. In 2007, Baek, et al. [13] presented two new Fuzzy-IBE schemes, in which the public parameters size is independent of the number of attributes. Later, Sarier [14] introduced a new and efficient biometric IBE (Bio-IBE) scheme and achieved better efficiency in terms of the decryption and key generation algorithms compared to [13]. In 2011, Sarier [15] proposed generic constructions for Bio-IBE that require no bilinear pairings. Recently, Qing [16] proposed a new Bio-IBE scheme in the standard model. In 2007, Burnett et al. [17] presented a biometric identity-based signature scheme in which the public key is constructed by a fuzzy extractor [18]. However, Sarier [19] showed that their scheme [17] cannot resist a type of denial of service attack and they proposed an improved scheme. In 2012, Li et al. [20] formalize the concept of biometric identity-based signcryption (Bio-IBSC) and proposed a Bio-IBC scheme in the random oracle model. Recently, Wang and Tang [21] proposed a novel biometric signcryption scheme that is identity-based and group-oriented.

All the above biometric signcryption schemes [20, 21] do not adopt the certificateless cryptography, and have the key escrow issue. In this paper, we extend the notion of biometric signcryption to the certificateless setting, and define the formal definition and security notion of the biometric certificateless signcryption (BCSC). We also proposed a concrete scheme of BCSC and formally prove its security in the random oracle model. Our BCSC scheme has the following advantages: (1) The scheme achieves forward secrecy, known session-specific temporary information security and public verifiability with confidentiality (PVC) security attributes; (2) The scheme only requires one bilinear pairing operation, and if there exits a proxy server between the sender and receiver, the users require no bilinear pairing operation since our scheme achieves PVC; (3) The scheme eliminates the certificate management complexity and key escrow issues.

The paper is organized as follows. Some background on bilinear pairings and hard problems are introduced in the next section. The formal models of BCSC are proposed in Section 3. Then, we propose a concrete BCSC scheme and provide a security proof for it in Section 4 and Section 5 respectively. In Section 6, a comparison is discussed with existing schemes. Finally, this paper ends with some concluding remarks.

II. PRELIMINARIES

In order to introduce the new biometric certificateless signcryption scheme, firstly, we review the required mathematical preliminaries and definitions. Then we describe the fuzzy extractor method.

A. Mathematical Preliminaries

Let \((G_1, +)\) and \((G_2, \cdot)\) be an additive and multiplicative group respectively of the same prime order \(q\). The bilinear pairing is a map \(\hat{e} : G_1 \times G_1 \rightarrow G_2\), which has the following properties.

1. Bilinear: \(\hat{e}(R, S)^y = \hat{e}(xR, yS)\) for all \(R, S \in G_1\) and \(x, y, \in \mathbb{Z}_q^*\)

2. Non-degenerate: There exists \(R, S \in G_1\) such that \(\hat{e}(R, S) \neq 1_{G_2}\)

3. Computable: There exists an efficient algorithm to compute \(\hat{e}(R, S)\) for all \(R, S \in G_1\)

The security of our biometric certificateless signcryption scheme is reduced to the well-exploited complexity assumptions, which are described as follows.

Definition 1. Elliptic Curve Discrete Logarithm Problem (ECDLP): For an integer \(k \in \mathbb{Z}_q\) and \(R, S \in G_1\), given \((R, S=kR)\), computing \(k\) is hard.

Definition 2. Computational Diffie-Hellman Problem (CDHP) in \(G_1\): For two integers \(x, y, \in \mathbb{Z}_q^*\) and a generator \(P\) of \(G_1\), given \((P, xP, yP)\), computing \(xyP\) is hard.

Definition 3. Modified Inverse Computational Diffie-Hellman Problem (MInv-CDHP) in \(G_1\): For two integers \(x, y, \in \mathbb{Z}_q^*\) and a generator \(P\) of \(G_1\), given \((P, xP, yP)\), computing \(x^{-1}yP\) is hard.

B. Fuzzy Extractor Method

Nowadays, many security systems use the user’s biometric information as his identity, such as fingerprint, voice command, retina scan, and so on. However, two biometric inputs are rarely identical. In order to solve this problem, Dodis et al. [18] showed how to generate cryptographic keys from biometric data, and proposed a new approach called fuzzy extractor, which can extract a unique string \(ID_U\) from biometric input \(w\) in a noise-tolerant way. In other words, suppose the biometric input changes to be \(\tilde{w}\) such that \(\text{dis}(w, \tilde{w}) \leq t\), the string \(ID_U\) can be reproduced exactly even if the approach is applied on a different \(\tilde{w}\), where \(\text{dis}\) is the distance metric used to measure the variation in the biometric reading and \(t\) is the noise tolerance parameter of the fuzzy extractor. Three following metrics were used in the fuzzy extractor approach.

1. Hamming metric: the number of symbol positions in which the biometric input \(w\) and \(\tilde{w}\) differ.

2. Set difference metric: size of the symmetric difference of two biometric input sets between \(w\) and \(\tilde{w}\).

3. Edit metric: the number of character insertions and deletions needed to convert \(w\) into \(\tilde{w}\).

Hamming metric is the most convenient metric and the other two are auxiliary. Based on the hamming metric, a cryptographic hash function \(H\) and a \([n, k, 2r+1]\) BCH (Bose-Chaudhuri-Hocquenghem) error correction code, Burnett et al. [17] proposed a concrete fuzzy extractor.

The definition of the fuzzy extractor is as follows:

Let \(M=\{0,1\}^*\) be a metric space with finite dimensions, a distance function \(\text{dis}\) is defined as \(M^* M^* \rightarrow \mathbb{Z}_7^*\) and a
hash function $H: \{0,1\}^n \rightarrow \{0,1\}^l$, where $l$ is the length of the extracted output string $ID_U$. The fuzzy extractor consists of two functions Gen and Rep.

**Gen:** The probabilistic generation procedure Gen on a biometric input $w \in M$ returns an extracted identity $ID_U = H(w)$ and a publicly reproduction parameter $PAR = w \oplus C(ID_U)$, where $w$ is a one-to-one encoding function.

**Rep:** The deterministic reproduction procedure Rep on a biometric input $w$ and the reproduction parameter $PAR$ outputs $ID_U = C_D(w \oplus PAR) = C_D(w \oplus w \oplus C(ID_U))$, where $D$ is a decoding function that has an error threshold of $t$ (can correct up to $t$-bit errors). If $\text{dis}(w, \tilde{w}) \geq t$, then $ID_U = ID_V$.

### III. FORMAL MODELS OF BIOMETRIC CERTIFICATELESS SIGNCRYPTION

In this section, we present the generic model and security model of biometric certificateless signcryption.

#### A. Generic Model

The model of biometric certificateless signcryption is constructed using the following five algorithms:

- **Setup:** On input of a security parameter $k$ the KGC uses this algorithm to output master secret key and some public parameters $prms$ for the system.

- **PartialKeyGen:** On input of a user $U$’s biometric data $w$, public parameters $prms$ and the master secret key, the KGC uses this algorithm to output the private key $D_U$ corresponding to $w$.

- **KeyGen:** Upon input of the user $U$’s biometric data $w$ and public parameters $prms$, the user $U$ uses this algorithm to output the secret value $x_U$ and the public key $PK_U$ for the user $U$.

- **Signcrypt:** To send a message $m$ to the receiver with biometric data $w_r$, secret value $x_r$ and private key $D_r$, the sender with biometric data $w_s$, secret value $x_s$ and private key $D_s$ runs this algorithm along with input $(m, w_s, w_r, x_s, D_s)$ to compute the signcryption message $\sigma$, where $\text{dis}(w_s, w_r) \geq t$.

- **UnSigncrypt:** When the receiver obtains the signcryption message $\sigma$, he uses this algorithm with input $(\sigma, w_s, w_r, x_r, D_r)$ to outputs either the plaintext message $m$ or the symbol $\bot$ according as whether $\sigma$ is a valid signcryption or not, where $\text{dis}(w_s, w_r) \geq t$.

The Signcrypt and UnSigncrypt algorithms have the following consistency constraint. If $\text{dis}(w_s, w_r) \geq t$, $\text{dis}(w_s, w_r) \geq t$ and $\sigma = \text{Signcrypt}(m, w_s, w_r, x_r, D_r)$, then we must have $m = \text{UnSigncrypt}(\sigma, w_s, w_r, x_r, D_r)$.

#### B. Security Model

In this section, we define the security notions of BCSC. A BCSC scheme should satisfy message confidentiality and unforgeability. There are two types of adversaries in our security model as follows:

- **Adversary $A_1$:** This type of adversary is allowed to obtain the KGC’s master secret key, but he can replace public key $PK_U$ with values of his choice.

- **Adversary $A_2$:** This type of adversary is allowed to obtain the master secret key but can not replace user’s public key $PK_U$.

**Definition 4 (Confidentiality).** A biometric certificateless signcryption (BCSC) scheme is said to have the indistinguishability against adaptive chosen ciphertext attacks (IND-BCSC-CCA2) if no polynomially bounded adversary $A_{i=1,2}$ has a non-negligible advantage in the following game.

- **Game – Initial:** The challenger $C$ runs the $\text{Setup}(k)$ algorithm, sends the system parameters to the adversary $A_i$, and sends the master secret key to the adversary $A_2$.

- **Phase1:** The adversary $A_i$ can make a polynomially bounded number of the following queries, where $A_i$ does not need to perform the PartialKeyGen and Replace Public Key query:

  - **PartialKeyGen query:** On a PartialKeyGen($w$) query for a user $U$, $C$ runs the PartialKeyGen algorithm to output the private key $D_U$ corresponding to $w$ and returns $D_U$ to $A_i$.

  - **KeyGen query:** On a KeyGen($w$) query for a user $U$, $C$ runs the KeyGen algorithm to output the secret value $x_U$ and the public key $PK_U$ adds $(w, x_U, PK_U)$ to the list $L_w$. Finally, $PK_U$ is returned.

  - **Replace Public Key query:** On input of a biometric data $w$ and a valid public key $PK_U$, $C$ replaces the public key corresponding to the $w$ with $PK_U$.

  - **Corruption query:** On a Corruption($w$) query for a user $U$, $C$ checks the list $L_w$ and returns the secret value $x_U$ to $A_i$. Note that if $C$ cannot answer the secret value of any biometric data $w$ for which corresponding public key has been replaced.

  - **Signcrypt query:** $A_i$ produces a sender’s biometric data $w_s$, a receiver’s biometric data $w_r$ and a plaintext message $m$. $C$ computes $\sigma = \text{Signcrypt}(m, w_r, w_s, x_r, D_r)$, then sends $\sigma$ to $A_i$.

  - **UnSigncrypt query:** $A_i$ produces a biometric data $w_s$, a receiver’s biometric data $w_r$ and a signcryption $\sigma$. $C$ sends the result of $\text{UnSigncrypt}(\sigma, w_s, w_r, x_r, D_r)$ to $A_i$.

  Note it is possible that the public key $PK_U$ or $PK_s$ has been replaced earlier by $A_1$ in Signcrypt or UnSigncrypt queries. If so, $A_i$ has to submit the corresponding secret value to $C$ for the consistency constraint.

  At the end of Phase1, $A_i$ generates a sender’s biometric data $w_{si}$, a receiver’s biometric data $w_{ri}$ and two plaintext messages $(m_s, m_t)$ on which he wishes to be challenged. He cannot make Corruption query on $w_t$ in Phase 1.

  - **Challenge:** The challenger selects a random bit $b$ from $\{0,1\}$ and computes $\sigma' = \text{Signcrypt}(m_b, w_{bi}, w_{ri}, x_{ri}, D_{ri})$, then sends $\sigma'$ to $A_i$.

  - **Phase 2:** $A_i$ can continue to ask the same queries that he made in the first phase. He is not allowed to make a Corruption query on $w_t$ such that $\text{dis}(w_t, w_{hi}) \geq t$, also he is not allowed to make an UnSigncrypt query on $\sigma'$ with biometric data $w_t$ and $w_{hi}$ unless the public key $PK_{ri}$ and $PK_{ri}$ has been replaced after the challenge phase.
as the master secret key,
\[ wA, wB = \oplus B \]
constructed using the following concrete algorithms:

**Game**

- **Initial**: The challenger \( C \) runs the Setup\((k)\) algorithm, sends the system parameters to the adversary \( A \), and sends the master secret key to the adversary \( A_2 \).
- **Probing**: \( A \) performs a polynomially bounded number of the queries just like in the Definition 1.
- **Forge**: \( A \) produces a forgery \( (w^*, w_{A2}, w_{B2}) \), where the signcryption \( \sigma \) is not generated by the signcryption oracle. \( A \) is not allowed to make a Corruption query on \( w \) such that \( \text{dis}(w, w_i) \equiv t \). \( A \) wins the game if the result of Unsiginycrypt\((w^*, w_{A2}, w_{B2}, D_A)\) is not the symbol \( \bot \).

IV. PROPOSED SCHEME

Our biometric certificateless signcryption scheme is constructed using the following concrete algorithms:

**Setup**: On input of a security parameter \( k \) the KGC chooses a bilinear pairing \( e : G_1 \times G_1 \rightarrow G_2 \) and four cryptographic hash functions \( H_1 : \{0,1\}^* \rightarrow \{0,1\}^t \), \( H_2 : \{0,1\}^t \rightarrow \{0,1\}^t \), \( H_3 : \{0,1\}^{2t} \rightarrow \{0,1\}^t \) and \( H_4 : \{0,1\}^{2} \rightarrow \{0,1\}^t \) and \( H_5 : \{0,1\}^{2} \rightarrow \{0,1\}^t \). The KGC randomly selects a master secret key \( s \in \mathbb{Z}_p \) and computes the corresponding key \( P_{pub} = s \cdot P \). The KGC also chooses a biometric feature extractor function \( B_I \) a one-to-one encoding function \( C_e \) and decoding function \( C_d \). The KGC secretly keeps the master secret key and publishes the public parameters of the system \( <G_1, G_2, e, \{P, P_{pub}, H_1, H_2, H_3, H_4, C_e, C_d, B_I> \).

**PartialKeyGen**: A communication user \( U \) obtains his biometric data \( w_U \) using the feature extractor function \( B_I \) and submits \( w_U \) to the KGC. The KGC computes \( ID_U = H_1(w_U) \) and \( D_{pub} = H_2(ID_U) \cdot P \) as the private key of the user.

**KeyGen**: A communication user \( U \) first picks randomly a number \( x_U \in \mathbb{Z}_p \), computes the public key \( PK_U = x_U \cdot P_{pub} \) and sets \( x_U \) as the secret value.

**SignCrypt**: When the sender with biometric data \( w_A \), public key \( PK_A \), secret value \( x_A \) and private key \( D_A \) needs to send a plaintext message \( m \) to the receiver with public parameter \( PAR_B \) and public key \( PK_B \), he performs the following steps.

1. Obtain a biometric data \( w_B \) of the receiver together with \( PAR_B \).
2. Compute \( ID_B = \text{Rep}(w_B, PAR_B) \).
3. Compute \( ID_A = H_1(w_A) \) and \( PAR_A = w_A \oplus C_e(ID_A) \).
4. Choose a random number \( t \in \mathbb{Z}_p \).
5. Compute \( R = x_U \cdot P_{pub} \) and \( v = e(D_A, P) \cdot H_1(ID_B) \).
6. Compute \( k_{IA} = H_2(x_A \cdot PK_A, x_A \cdot PK_B, v) \).
7. Compute \( c = m \oplus k_{IA} \) and \( h = H_2(c, R) \).
8. Compute \( S = x_A \cdot (D_A + h \cdot x_A \cdot H_2(ID_A) \cdot PK_A) \).
9. Send the signcryption message \( \sigma = (c, R, S, PAR_B) \).

**UnsignCrypt**: When receiving \( \sigma = (c, R, S, PAR_B) \), the receiver with secret value \( x_B \) and private key \( D_B \) does the following steps.

1. Obtain a biometric data \( w_A \) of the sender together with \( PAR_A \).
2. Compute \( ID_A = \text{Rep}(w_A, PAR_A) \).
3. Compute \( h = H_2(c, R) \).
4. Check if \( \hat{e}(1, H_1(ID_A), R, S) \cdot \hat{e}(P, P) \cdot \hat{e}(PK_A, PK_A)^v \).
5. If the check fails, return \( \bot \). Else, perform following steps.
6. Compute \( v = \hat{e}(D_B, P) \).
7. Compute \( k_{IA} = H_2(x_A \cdot R, x_A \cdot PK_A, v) \).
8. Recover \( m = m \oplus k_{IA} \).

**V. Security Analysis**

In this section, we use the random oracle model to analyze the confidentiality and unforgeability security attributes of our BCSC scheme based on the Computational Diffie-Hellman Problem and Modified Inverse Computational Diffie-Hellman Problem.

A. Basic Security

**Theorem 1**: Assuming that the CDHP is hard, the advantage of any IND-BCSC-CCA2 adversary \( A \) against our biometric certificateless signcryption scheme is negligible in the random oracle model.

**Proof**: On receiving the CDHP challenge tuple \( (P, aP, bP) \), where \( P \) is the generator of \( G_1 \), the goal of the distinguisher \( C \) is to compute \( abP \). The challenger \( C \) chooses a random number \( s \in \mathbb{Z}_p \), as the master secret key, sets \( P_{pub} = s \cdot P \), sends the system parameters to \( A \), and sends the master secret key to \( A_2 \). The \( C \) answers a polynomially bounded number of queries as follows.

**H_1 queries**: \( A \) picks the biometric data \( w \). \( C \) sets \( ID_A = H_1(w) \), adds the tuple \( (w, ID_A) \) to a list \( L_1 \) which is initially empty and answers \( h_1 \).

**H_2 queries**: \( A \) picks the biometric data \( w \). We will assume that \( A_1 \) makes the query \( H_1(w) \) before it makes the \( H_2(w) \) query. \( C \) searches an element \( (w, ID_A) \) in the list \( L_1 \) and sets \( h_2 = H_2(ID_A) \). It then adds the tuple \( (w, h_2) \) to a list \( L_2 \) which is initially empty and answers \( h_2 \).

**H_3 queries**: \( C \) checks if there exists \( (K_1, K_2, K_3, h_3) \) in a list \( L_3 \) which is initially empty. If such a tuple is found, \( C \)
returns $h_i$, otherwise he returns $A_i$ by a random binary sequence $h_i \in \{0,1\}^\rho$ and puts the $(k_1, k_2, k_3, h_i)$ into $L_3$.

**H_3 queries:** C checks if there exists $(c, R, h_d)$ in a list $L_4$ which is initially empty. If such a tuple is found, C returns $h_d$, otherwise he returns $A_i$ by a random number $h_i \in Z$; and puts the $(c, R, h_d)$ into $L_4$.

**PartialKeyGen queries:** $A_i$ picks the biometric data $w$. C checks if there exists $(w, u, D)$ in a list $L_3$ which is initially empty. If such a tuple is found, C returns $D_i$ otherwise, C selects a number $u \in Z^*$ at random and computes $D_i = uP$. Then returns $D_i$ and adds the $(w, u, D_i)$ into $L_5$.

**KeyGen queries:** $A_i$ picks the biometric data $w$. C chooses an index $l \in \{1, 2, \ldots, q_k\}$ first (suppose that C can answer at most $q_k$ KeyGen queries). On the $l$-th query, if $i=l$, C sets $w_i = w$, $x_i = 1$ and $PK_i = bP_{pub}$. Otherwise, C chooses a number $x_i \in Z^*$ at random and sets $PK_i = x_iP_{pub}$. In these two cases above, C adds the tuple $(w, x_i, PK_i)$ to a list $L_6$ which is initially empty and answers $PK_i$.

**Replace Public Key query:** $A_i$ picks the biometric data $w$ and a valid corresponding public key $PK_i$. C updates $L_6$ with the tuple $(w, x_i, PK_i)$ and answers $x_i$.

**Signcrypt queries:** $A_i$ picks the sender’s biometric information $w_m$, the receiver’s biometric information $w_r$ and a plaintext message $m$. We will assume that $A_i$ makes the query Signcrypt$(w_m)$ before he makes the Corruption$(w_r)$ query. If $w = w_m$, then C aborts the simulation. Otherwise, C searches the list $L_6$ for the entry $(w, x_i, PK_i)$ and answers $x_i$.

**Unsigncrypt queries:** $A_i$ picks the sender’s biometric information $w_m$, the receiver’s biometric information $w_r$ and a signcryption message $\sigma = (c, R, S, PAR^r)$ on some message $m'$ from the sender $w'_1$ to the receiver $w'_2$. $C$ calls the KeyGen query on $w'_i$ and checks if $w'_i = w_i$ and if this is not the case he aborts; otherwise he obtains $\sigma = (c, R, S, PAR^r)$ and then randomly chooses $S \in G_3$, $b \in \{0,1\}$ and sets $R = aP$, computes $v = e(D'_1, P)^b_{ID_2}$, and obtains $k_{ab} = H_2(\xi, x; bP_{pub}, v')$ (where $\xi = abP$ is the candidate for the CDHP). Finally, $C$ computes $c = m_b \oplus k_{ab}$ and sends the signcryption message $\sigma = (c, R', S', PAR^r)$ to $A_i$.

In the phase 2, $A_i$ performs a series of queries as in the phase 2. At the end of the simulation, he selects a bit $b'$ for which he believes the relation $\sigma' = (c', R', S')$ holds. If $b \neq b'$, $C$ fails the game. If $b = b'$, $C$ will win the game due to he can recognize which message was signcrypted by seeing the signcryption alone with the session key $k_{ab} = H_2(\xi, x; bP_{pub}, v')$, where $\xi = abP$.

So, if the adversary A can defeat our BCSC scheme by learning something about the signcryption message, that means there exists an efficient algorithm to solve the CDHP with non-negligible advantage. However, so far, the probability of any polynomial-time algorithm to solve CDHP is negligible. Hence, our BCSC scheme is secure against any IND-BCSC-CCA2 adversary $A_i$ attack.

**Theorem 2 (Unforgeability).** Assuming that the Minv-CDHP is hard, the advantage of any EUF-BCSC-CMA adversary $A_i$ against our biometric certificateless signcryption scheme is negligible in the random oracle model.

**Proof.** On receiving the Minv-CDHP challenge tuple $(P, aP, bP)$, where $P$ is the generator of $G_1$, the goal of the distinguisher $C$ is to compute $a^i b^j P$. The challenger $C$ chooses a random number $s \in Z^*$ as the master secret key, sets $P_{pub} = sP$, sends the system parameters to $A_i$ and sends the master secret key to $A_2$. The $C$ answers a polynomially bounded number of queries as follows.

**KeyGen queries:** $A_i$ picks the biometric data $w$. C chooses an index $l \in \{1, 2, \ldots, q_k\}$ first (suppose that $C$ can answer at most $q_k$ KeyGen queries). On the $i$-th query, if $i=l$, C sets $w_i = w$, $x_i = 1$ and $PK_i = bP_{pub}$. Otherwise, C chooses a number $x_i \in Z^*$ at random and sets $PK_i = x_iP_{pub}$. In these two cases above, C adds the tuple $(w, x_i, PK_i)$ to a list $L_6$ which is initially empty and answers $PK_i$.

**H_1, H_2, H_3, H_4, PartialKeyGen, Replace Public Key, Corruption, Signcrypt, Unsigncrypt queries:** these queries are the same as the Theorem 1.

Eventually, $A_i$ chooses a valid forgery signcryption message $\sigma' = (c', R', S', PAR^r)$ on some message $m'$ from the sender $w'_1$ to the receiver $w'_2$. $C$ calls the KeyGen query on $w'_1$ and checks if $w'_1 = w_1$ and if this is not the case he aborts; otherwise he obtains $\sigma' = (c', R', S', PAR^r)$ and then randomly chooses $S \in G_3$, $b \in \{0,1\}$ and sets $R = aP$, computes $v = e(D'_1, P)^b_{ID_2}$, and obtains $k_{ab} = H_2(\xi, x; bP_{pub}, v')$ (where $\xi = abP$ is the candidate for the CDHP). Finally, $C$ computes $c' = m_{b'} \oplus k_{ab}$ and sends the signcryption message $\sigma' = (c', R', S')$ to $A_i$.
\[= H_2(ID)^{-1}(h-h')^{-1}(h-h')x_1H_2(ID)x_PK';\]

So, if the adversary \( A \) can forge a valid signcryption message of our BCSC scheme by learning something about the signcryption message, that means there exists an efficient algorithm to solve the MInv-CDHP with non-negligible advantage. However, so far, the probability of any polynomial-time algorithm to solve MInv-CDHP is negligible. Hence, our BCSC scheme is secure against any EUF-BCSC-CMA adversary \( A \) attack.

**B. Further Security Considerations**

In this subsection we will heuristically argue that our biometric certificateless signcryption scheme achieves the following two security properties and show that Li et al’s scheme [20] does not satisfy these security properties.

1. **Forward Secrecy (FS):** In our BCSC scheme, compromise of the \( i \)-th decryption key \((k_{iA})=H_2(x_PK_B, x_PK_B, v)\) will not affect the secrecy of the later \( j \)-th decryption key \((k_{iB})\). Further, suppose the adversary obtains the sender’s private key \( D_A \) or receiver’s private key \( D_B \) does not affect the secrecy of the \( j \)-th signcryption message and cannot recover the plaintext \( m \). For the adversary, he can compute the value \( v \), but he can’t compute \( x_PK_B \) or \( x_PK_B \). Given \((R_B, PK_B)\), it is hard to compute \( x_PK_B \) or \( x_PK_B \) under the assumption of CDHP and it is hard to compute \( x \) or \( x \) under the assumption of ECDLP. Hence, our BCSC scheme satisfies the forward secrecy. But in Li et al’s scheme [20], if the receiver’s private key \( S_{PB} \) is compromised by the adversary, then the adversary can compute the decryption key \( r=g^r \) and can recover the plaintext \( m=c \oplus H_3(r) \).

2. **Known session-specific temporary information security (KSSTIS):** Compromising the sender’s ephemeral key does not enable the adversary to obtain the decryption key. Specifically, for our BCSC scheme, obtaining the sender’s ephemeral key \( x \) allows the adversary \( A \) to compute \( x_PK_B \) and the adversary \( A \) can compute the value \( v \). However, the adversary \( A \) still cannot compute the encryption key \( k_{iB}=H_2(x_PK_B, x_PK_B, v)\), since it is hard to obtain the value \( x_PK_B \) or \( x_PK_B \). Given \((PK_B, PK_B)\), it is hard to compute \( x_PK_B \) or \( x_PK_B \) under the assumption of CDHP and it is hard to compute \( x \) or \( x \) under the assumption of ECDLP. Hence, our BCSC scheme satisfies the KSSTIS security property. But in Li et al’s scheme [20] if the sender’s ephemeral key \( x \) is compromised by the adversary, then the adversary can compute the decryption key \( r=g^r \) and can recover the plaintext \( m=c \oplus H_3(r) \).

**VI. PERFORMANCE ANALYSIS**

In this section, we compare our BCSC scheme with the Li et al’s biometric identity-based signcryption scheme in Table 1. We assume that two schemes use the same parameters \(<G_1, G_2, e, \tilde{e}>\) as defined in Section 2.

In the “security” column, the notations FS, KSSTIS and PVC refer to the forward secrecy, known session-specific temporary information security and public verifiability with confidentiality security properties respectively. Y denotes that the scheme provably achieves the security and N denotes that it does not satisfy this security.

In the “Computation Cost” column, the notations “Signcryption” and “Unsigncryption” refer to the overall computation costs not including precomputation overheads required in the Signcrypt and Unsigncrypt algorithms respectively, and we let MUL be the number of point scalar multiplications in the group \( G_1 \), EXP be the number of exponentiations in the group \( G_2 \) and PAI be the number of bilinear pairing computations.

From the Table 1, we can see that our BCSC scheme only requires one bilinear pairing operation, and if there exits a proxy server between the sender and receiver, the user requires no bilinear pairing operation since our scheme achieves PVC. As we all know, bilinear pairing

<table>
<thead>
<tr>
<th>Scheme</th>
<th>Security</th>
<th>Computation Cost</th>
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<tbody>
<tr>
<td></td>
<td>FS KSSTIS PVC</td>
<td>Signcryption Unsigncryption</td>
</tr>
<tr>
<td>Li’s scheme[12]</td>
<td>N N</td>
<td>3MUL+EXP MUL+EXP+2PAI</td>
</tr>
<tr>
<td>Our scheme</td>
<td>Y Y</td>
<td>4MUL+EXP 2MUL+2EXP+PAI</td>
</tr>
</tbody>
</table>

TABLE I. A COMPARISON OF EFFICIENCY
computation in general is the most expensive operation in a signcryption scheme from bilinear pairing, although Li et al’s scheme [20] has less multiplications and exponentiations computations, the computation time of our BCSC scheme is better since the time for 2MUL+2EXP is more than the time for one bilinear pairing operation. Moreover, our BCSC scheme satisfies the forward secrecy, known session-specific temporary information security and public verifiability with confidentiality security properties.

VII. CONCLUSIONS

In this paper, we define the formal notion of biometric certificateless signcryption and propose a concrete BCSC scheme from bilinear pairing. Our scheme admits a security analysis in the random oracle model. Moreover, The scheme only requires one bilinear pairing operation, and if there exits a proxy server between the sender and receiver, the users require no bilinear pairing operation since our scheme achieves public verifiability with confidentiality. Considering the resource-constrained communication devices and the communication networks with high security requirements, it may be that our biometric certificateless signcryption scheme is more applicable.

ACKNOWLEDGMENT

The authors would like to thank the reviewers for giving valuable suggestions and comments. This work is supported by the National Natural Science Foundation of China under grant no. 11226042, the Science and Technology Supporting Program of Jiangxi Province under grant no. 2012ZBBE50036 and the Science and Technology Project of Jiangxi Provincial Department of Education under grant no. GJJ12147.

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