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# An Identity-Based Signcryption on Lattice without Trapdoor

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**Abstract:** Identity-based signcryption schemes based on large integer factorization and discrete logarithm problems were considered to be insecure for the quantum computer attack. Thus, choosing a quantum-resist platform and constructing secure schemes based on new hard assumptions are challenges. In this paper, we propose an alternative scheme — an identity-based signcryption on lattice, which does not need to rely on a trapdoor. Meanwhile, our scheme achieves IND-CCA2 and sUF-CMA security, and it is also secure against the current quantum algorithm attacks based on LWE problem for lattice. Furthermore, we demonstrate that the newly proposed scheme has much shorter secret key size, and higher speeds in signcryption and unsigncryption stages, compared with some exiting identity-based signcryption schemes.

**Key Words:** Identity based signcryption, Quantum attack, Lattice, Unforgeability
**Category:** L.4.0

## 1 Introduction

Signcryption as an important cryptographic primitive, which can simultaneously achieve public key encryption and signature in one logical step. In 1997, Zheng initially introduced signcryption that combined digital-signature with public-key algorithm, whose cost is greatly reduced than those sign-then-encrypt schemes [Zheng 1997]. Since signcryption provides confidentiality, integrity, authentication of information and non-repudiation. Then it can be used in many applications, such as electronic transaction protocol [Tan et al., 2018A, Zhang 2018A], mobile agent protocol [Groba et al., 2018, Zhang et al., 2018B], content protection [Yu et al., 2018A], key management [Anzani et al., 2017] and routing protocol. Due to its confidentiality and authentication, signcryption plays an important role in cloud computing [Shen 2018A, Xue et al., 2019, Yu et al., 2018B, Yang et al., 2018] and Internet of things [Stergiou et al., 2018, Guan et al., 2017, Alaba et al., 2017, Yu et al., 2019], where users can further reduce the local computational cost based on cloud computing and data sharing [Lyu et al., 2017, Mollah et al., 2017, Jindal et al., 2018, Pitchai et al., 2016] by combining with some proxy computing technologies. In addition, since there is no need to maintain users' public-key list in identity-based public key algorithms [Shamir 1984, Li et al., 2015A, Yu et al.,2017, Li et al., 2019], some identity-based signcryption schemes were proposed with lower computation and communication cost [Malone-Lee 2002, Libert and Quisquater, 2003, Chow et al., 2003, Boyen 2003, Barreto et al., 2005]. However, with rapid development of the quantum computing [Shor 1997], the cryptographic schemes based on the cryptographic intractable problems on number theory have been threatened, then the quantum attacks also bring risks to those signcryption schemes based on large integer factorization and discrete logarithm problem, etc.

To resist the current quantum algorithm attacks, lattice-based public key cryptosystems have become the most active branch of anti-quantum cryptography. Lattices provided researchers with rich cryptographic hard assumptions such as learning with errors (LWE), small integer solution (SIS), shortest vector problem (SVP) and shortest independent vector problem (SIVP), where the researchers have built a reduction between the LWE problem and hidden subgroup problem on dihedral group, and the hidden subgroup problem has been proved to be secure against quantum attacks. Based on these hard problems on lattices, lattice-based signcryptions were proposed. In 2012, Li et al [Li et al., 2013] constructed a lattice-based signcryption scheme that has the characteristics of fast computing on lattices. The scheme achieves adaptively indistinguishability against chosen ciphertext attacks (IND-CCA2) and existentially unforgeability chosen message attacks (eUF-CMA). In 2013, Yan et al [Yan et al., 2013] designed a novel lattice-based signcryption scheme, and the security can be proved in the standard model. In this scheme, Yan et al presented an efficient trapdoor generation algorithm, and used Chameleon hash function to remove the trapdoor and construct a challenge tuple in the proof. Compared with the schemes in the random oracle model at that time, Yan's signcryption algorithm is more efficient. In 2014, Lu et al [Lu et al., 2014] gave a lattice-based signcryption scheme, where the security of encryption algorithm is based on the LWE problem and the security of signature depends upon the SIS problem. However, almost all lattice-based schemes cannot show the high asymptotic computation efficiency. The main reason is that the dimension of the lattice must be very large to meet the security requirements. The rank of the lattice is generally 200, while the dimension of the lattice is over 54 thousand. Then, one-time encryption (or signature) needs about 10 million modular multiplications. In particular, the signature algorithm based on the original image sampling is the most time-consuming. In sum, to propose a more secure and efficient lattice-based scheme, on one hand, we need to construct good lattices to realize the security without large dimensions; on the other hand, we should seek new methods to design efficient signcryption schemes.

In this paper, we provide an alternative method for constructing an identity-based signcryption (IBSC) scheme on lattice. Inspired by [Lyubashevsky 2012, Tian and Huang 2016], we remove the use of trapdoor in our scheme and prove that the scheme achieves IND-CCA2 and sUF-CMA security. Meanwhile, it is also secure against the current quantum algorithm attacks based on LWE problem for given lattices. Furthermore, we analyze its efficiency by comparing with some exiting identity-based signcryption schemes. Our scheme has the following merits:

– (a) The newly proposed scheme has much shorter secret key size than those of the schemes in [Li et al., 2013, Yan et al., 2013];

– (b) It has higher speeds in signcryption and unsigncryption stages than that of scheme in [Yan et al., 2013].

Organization. In Section 2, we introduce the definitions of lattice and IBSC. Section 3 shows how to construct IBSC schemes. In Section 4, we present the security of proposed scheme, and then compare our scheme with other IBSC schemes. Finally, we draw conclusions in Section 5.

## 2 Preliminaries

### 2.1 Definitions of Lattice and Important Tools

In this section, we will present the knowledge of lattice and some important tools, which can be seen from [Lyubashevsky 2012, Zhu et al., 2017].

Definition 2.1 (Lattice). linearly independent vectors $d_1, d_2, ..., d_n$ are denoted as the a basis of lattice, which can also be denoted as a Matrix $\boldsymbol{D}$. The generated lattice can be written as $\Lambda(\mathrm{D}) = \Lambda(d_1, d_2, ..., d_n) = \{\boldsymbol{D}x | x \in \mathbb{Z}_n\}$.

Definition 2.2 ($q$-ary lattice). $q$ is a prime, $\boldsymbol{D} \in \mathbb{Z}_q^{n\times m}$. $\mathcal{L}^{\perp}(\boldsymbol{D}) = \{e \in \mathbb{Z}^n : \boldsymbol{De} = 0(mod\ q)\}$ is $q$-ary lattice.

Definition 2.3 ($SIS_{q,n,m,\beta}$ [Lyubashevsky 2012] ). For a matrix $D \leftarrow \mathbb{Z}_q^{n\times m}$, SIS is to find a $\boldsymbol{v} \in \mathbb{Z}^m$ satisfying $\boldsymbol{Dv} = 0, \boldsymbol{v} \leq \beta, \beta \in \mathbb{R}, q \in \mathbb{Z}^+$.

Let $q \geq 2$ be an integer and let $\chi$ on $\mathbb{Z}_q$, the LWE's decision version $LWE_{q,\chi}$ is to differentiate between the distribution $A_{s,\chi}$ and the distribution on $\mathbb{Z}_q^n \times \mathbb{Z}_q$ of the variable $(\alpha, \alpha^T s + x)$, here $\alpha \leftarrow \mathbb{Z}_q^n$ is uniform and $x \leftarrow \chi$ obeys gaussian distribution. The LWE problem's standard version is finding $s \in \mathbb{Z}_q^n$ given access to any desired $poly(n)$ number of samples from $A_{s,\chi}$ for some arbitrary $s$.

Definition 2.4 (Discrete Gaussian Distribution) Define $\forall s > 0$, $y \in \mathbb{R}^N$, $c$ as Gaussian distribution's center. The Gaussian function is denoted as $\rho_{s,c}(x) = exp(\frac{-\pi||y-c||^2}{s^2})$. Then the discrete Gaussian distribution on $\Lambda$ is $D_{\mathcal{L},s,c}(y) = \frac{\rho_{s,c}(y)}{\rho_{s,c}(\mathcal{L})}$.

Theorem 2.5 (Rejection Sampling Theorem). Define $V$ as one of $\mathbb{Z}^m$'s subset, the elements' norm of $V$ are not greater than T, $\sigma = \omega(T\sqrt{logm})$ is the element in $\mathbb{R}$, M is a constant, $h : V \to \mathbb{R}$ is a probability distribution. There are two algorithms. The first algorithm is described as $v \leftarrow h, z \leftarrow D_{v,\sigma}^m, generate(z, v)$ with probability $min(\frac{D_\sigma^m(z)}{MD_{v,\sigma}^m(z)}, 1)$. The other algorithm is such that $v \leftarrow h, z \leftarrow D_\sigma^m, output(z, v)$ with probability $\frac{1}{M}$. Then the first algorithm' distribution does not exceed the second algorithm's statistical distance $\frac{2^{-\omega(logm)}}{M}$. Meanwhile, The first one can output something with probability greater than $\frac{1-2^{-\omega(logm)}}{M}$.

### 2.2 Identity-based Signcryption Scheme

An IBSC scheme is constitute of four algorithms($ST_\varepsilon, EX_\varepsilon, SC_\varepsilon$, $US_\varepsilon$), we denotes $\mathcal{S}$ and $\mathcal{R}$ respectively as sender and receiver, $params$ and $mk$ as system parameters and master key respectively, and $sk_{id_i}$ as private key. The definition is described as follows.

– $ST_\varepsilon(1^n)$ generates $params$ and $mk$.

– $EX_\varepsilon(params, mk, id)$ produces $sk_{id_i}$ according to one's identity $id_i$, $i = \mathcal{R}$ or $\mathcal{S}$.

– $SC_\varepsilon(id_{\mathcal{R}}, m, sk_{\mathcal{S}})$ outputs a ciphertext $\sigma$.

– $US_\varepsilon(params, id_{\mathcal{S}}, sk_{\mathcal{R}}, \sigma)$ recovers the initial message $m$ if $\sigma$ passes the verification, otherwise reject it.

IBSC must meet the conditions of confidentiality and authenticity, i.e., confidentiality means the IBSC scheme can be indistinguishable to defeat adaptive chosen ciphertext attacks (IND-CCA2) [Malone-Lee 2002]. Meanwhile, the authenticity means IBSC scheme can be strong unforgeable against adaptive chosen message attacks (sUF-CMA).

Definition 2.4 (IND-CCA2). Define $C$ as challenger, an IBSC scheme is IND-CCA2 secure if no PPT adversary $\mathcal{A}$ can win the IND-CCA2 game with negligible probability.

- Setup: $C$ executes $ST(1^k)$ to produce $(mpk, msk)$ and run $\mathcal{A}$ as its subprogram.
- Phase 1: The adversary $\mathcal{A}$ can perform any number queries of polynomial bound in an adaptive method.
- ET queries: $\mathcal{A}$ selects one $id$. $C$ runs algorithm $ET(id)$ to produce $S_{id}$ and send it to $\mathcal{A}$.
- SC queries: $\mathcal{A}$ chooses one $id_s$, one $id_r$ and a message $m$. $C$ runs $ET(id_s)$ to generate $S_{id_r}$, runs $SC(m, S_{id_s}, id_r)$ to generate encrypted message $\psi$, and then delivers $\psi$ to $\mathcal{A}$.
- US queries: $\mathcal{A}$ chooses $id_s$, $id_r$, and a encrypted message $\psi$. $C$ runs $ET(id_r)$ to generate $S_{id_r}$, runs $US(\psi, S_{id_r}, id_s)$ to recover the original message, and delivers it to $\mathcal{A}$.
- Challenge: $\mathcal{A}$ can decide when to end Phase1. $\mathcal{A}$ will choose $m_0$ and $m_1$, $id_s^*$, and $id_r^*$. $id_r^*$ could not be queried in $ET$ in Phase 1. $C$ can randomly chooses a bit $p$ from $\{0,1\}$, runs $SC(m_\delta, s_{id_s^*}, id_r^*)$ to output $\psi^*$, and then deliver $\psi^*$ to $\mathcal{A}$.
- Phase 2 : $\mathcal{A}$ can execute any times of queries of a polynomial bound adaptively again as in Phase1, we assume that $id_r^*$ will not be queried in $EX$ query and $\psi^*$ will not be queried by $US$ queries.
- Guess: $\mathcal{A}$ will output a bit $p^{'}$. If $p^{'}$ equals to $p$, then $\mathcal{A}$ wins.

  $\mathcal{A}$'s advantage is denoted as $Adv(\mathcal{A}) = [Pr[p^{'} = p] - 1/2]$, here $Pr[p^{'} = p]$ is the probability of $p^{'} = p$.

Definition 2.5 (sUF-CMA). An IBSC is sUF-CMA secure, if no PPT adversaries $\mathcal{A}$ can win sUF-CMA game with a negligible probability.

- Setup: $C$ execute runs $ST(1_k)$ to produce $(mpk, msk)$ and runs $\mathcal{A}$ as its subroutine.

- Attack: $\mathcal{A}$ executes a number queries of a polynomial bound like in IND-CCA2 game.
- Forgery: $\mathcal{A}$ produces a tuple $(m^*, \psi^*, id_s^*, id_r^*)$. Here, we assume $id_s^*$'s private key will not be queried, also $\psi^*$ will not be returned by SC oracle when querying $m^*, S_{id_r^*}, id_s^*$ in attack phase. if $US(\psi^*, S_{id_r^*}, id_s^*)$ does not output $\perp$ , then $\boldsymbol{A}$ wins.

The advantage of $\mathcal{A}$ is defined as the probability that it wins.

## 3 Our IBSC scheme

Now we will introduce a new IBSC $\varepsilon = (ST_\varepsilon, EX_\varepsilon, SC_\varepsilon, US_\varepsilon)$. In the beginning, we will define some denotations as follows: $\mathcal{S}$, $\mathcal{R}$ are respectively the sender and the receiver. Private Key generator is short for PKG, $q \geq 3$ is a prime, $M$ is a real. $m > 5nlogq$, $k$, and $\lambda$ are positive integers. $\tilde{L} = O(\sqrt{nlogq})$ is the bound, $s = \tilde{L}\omega(\sqrt{logn})$ is gaussian parameter, $\sigma = 12s\lambda m$ is standard deviation.

Then the detailed scheme is described as follows:

(1) $ST_\varepsilon(1^n)$

- The algorithm runs $TrapGen(q, n)$ [Tian and Huang 2016] to obtain $\boldsymbol{A} \in \mathbb{Z}_q^{n\times m}$ with lattice $\Lambda^\perp(\boldsymbol{A})$'s one basis $\boldsymbol{D} \in \mathbb{Z}_q^{n\times m}$ satisfying $\tilde{L} \geq ||\tilde{\boldsymbol{D}}||$.
- The algorithm Chooses hash: $H : \{0,1\}^* \to \{v : v \in \{-1,0,1\}^k, ||v||_1 \leq \lambda\}$, $H_1 : \{0,1\}^* \to \mathbb{Z}_q^{n\times k}$ and $H_2 : \{0,1\}^* \to \mathbb{Z}_q^{n\times k}$.
- The algorithm will generate $paras = (\boldsymbol{A}, H, H_1, H_2)$ and master private key $msk = \boldsymbol{D}$.

(2) $ET_\varepsilon(paras, msk, id_i)$

PKG run algorithm $SampleMat(A, D, s, H_1(id_i))$ [Tian and Huang 2016] to obtain a signing key $sk_{id_i} = S_{id_i} \in \mathbb{Z}^{m\times k}$, here $i = \mathcal{S}$ or $\mathcal{R}$. $S_{id_i}$ should satisfy

$$\begin{cases} AS_{id_i} = H_1(id_i) \\ ||S_{id_i}|| \leq s\sqrt{m} \end{cases} \tag{1}$$

(3) $SC_\varepsilon(m, S_{id_\mathcal{S}}, id_\mathcal{R})$

Given $paras$, $m \in \{0,1\}^*$, $\mathcal{S}$'s secret key $S_{id_\mathcal{S}}$, and receiver's identity $id_\mathcal{R}$.

- $\mathcal{S}$ selects a random $y \leftarrow D_\sigma^m$ and computes

$$r = H_2(Ay, H_1(id_\mathcal{R})) \tag{2}$$

– $\mathcal{S}$ computes

$$c = H(r, AS_{id_{\mathcal{S}}}) \bigoplus m \tag{3}$$

– $\mathcal{S}$ computes

$$z = S_{id_{\mathcal{S}}} r + y \tag{4}$$

– Then $\mathcal{S}$ outputs (c,z) with probability $min(\frac{D_\sigma^m(z)}{MD_{\sigma, S_{id_{\mathcal{S}}}h}(z)}, 1)$. The signature tuple is (r,c,z).

(4) $US_\varepsilon((r, c, z), id_{\mathcal{S}}, S_{id_{\mathcal{R}}})$
$\mathcal{R}$ will compute

$$h = H_2(Az - H_1(id_{\mathcal{S}})r, AS_{id_{\mathcal{R}}}) \tag{5}$$

and then $\mathcal{R}$ can get the original message

$$m = H(h, H_1(id_{\mathcal{S}})) \bigoplus c \tag{6}$$

If equation 7 are true, we accept the original message. Otherwise, we reject it.

$$\begin{cases} ||z|| \leq 2\sigma\sqrt{m} \\ h = r \end{cases} \tag{7}$$

## 4 Security and Performances

In this section, we will analyze the security of our IBSC scheme, then we compare our scheme with other IBSC schemes in terms of performances.

### 4.1 Correctness and Security

Theorem 1 (Correctness) our IBSC scheme satisfies correctness.

Proof. According to our IBSC scheme's construction process, we can obtain $Az - H_1(id_s)r = A(S_{id_s}r + y) - H_1(id_s)r = AS_{id_s}r + Ay - H_1(id_s)r = Ay$. Also we can get $AS_{id_r} = H_1(id_r)$.

Therefore, $H_2(Az - H_1(id_s)r, AS_{id_r}) = H_2(Ay, H_1(id_r))$. We can get the original message by computing $H(h, H_1(id_s)) \bigoplus c$. If $h = r$, we output the message $m$, otherwise we reject it.

By using lemma 2 and Lemma 3 described in [Xie et al., 2016], $z$ is close to a vector from $D_\sigma^m$. Thus, we can get $||z|| \leq 2\sigma\sqrt{m}$ with probability at least $1 - 2^{-m}$.

Theorem 2 (IND-CCA2) if an adversary $\Gamma$ can win IND-CCA2 games in a time $t$ with non-negligible advantage $\varepsilon$ after $q_e$ times ET queries, $q_s$ times SC queries, $q_u$ times US queries, and $q_{H_1}, q_{H_2}, q_H$ queries respectively to oracles $H_1, H_2, H$, there has a polynomial algorithm $C$ who can solve $LWE$ problem with advantage $\epsilon^{'} \geq \epsilon - q_H q_u / 2^n$ in time $t^{'} < t + (q_u + q_H)t_H + q_u t_{H_2}$.

Proof. in the beginning, we assume adversary $\Gamma$ can win IND-CCA2 game with non-negligible probability $\varepsilon$, then we can construct an algorithm $C$ who can run $\Gamma$ as its subprogram.

Suppose the challenger $C$ receives a random LWE instance $(\tilde{S}, \tilde{z} = \tilde{S}\tilde{r} + \tilde{y})$, his goal is to compute $\tilde{S}$. $C$ can run $\Gamma$ as its subprogram to get $\tilde{S}$ and be a challenger in the game.

Setup: Suppose $C$ runs algorithm $ST_\epsilon$ to generate $params = A, H, H_1, H_2, H$ and master secret key $msk = B$. Then $C$ delivers $paras$ to $\Gamma$.

Phase 1: $C$ holds lists $L_1, L_2, L$ to simulate $H_1, H_2, H$ oracles respectively, and replies for the queries as belows:

$H_1$ oracle: once receiving $id_i$ query $(1 \leq i \leq q_{h_1})$, $C$ will initially check whether there exists a corresponding value $H_1(id_i)$ in $L_1$. If there exists, $H_1(id_i)$ will be returned. Otherwise, $C$ will select a random $h_{1_i} \in \mathbb{Z}_q^{n \times k}$, stores $(id_i, h_{1_i})$ into $L_1$, then $C$ will return $h_{1_i}$ to $\Gamma$.

$H_2$ oracle: once receiving $Ay_i, h_{2_i}$ query $(1 \leq i \leq q_{h_2})$, $C$ will initially check whether there exists a corresponding value $h_{2_i}$ in $L_2$. If there exists, $h_{2_i}$ will be returned. Otherwise, $C$ will select a random $h_{2_i} \in \mathbb{Z}_q^{n \times k}$, stores $(Ay_i, id_i, h_{1i}, h_{2i})$ into $L_2$, and returns $h_{2i}$ to $\Gamma$.

$H$ oracle: once receiving $r_i, AS_i)$ query $(1 \leq i \leq q_H)$, $C$ will initially check whether there exists a corresponding $H_i$ in $L$. If there exists, $H_i$ will be returned. Otherwise, $C$ will select a random $h_i \in \mathbb{Z}_q^{n \times k}$, inserts $(r_i, AS_i, h_i)$ into $L$, and returns $h_i$ to $\Gamma$.

$EX_\epsilon$ query: When $\Gamma$ queries $id_i(1 \leq i \leq q_e)$ to get a secret key, $C$ will initially search in $L_1$, if there exists a corresponding value for $id_i$, $C$ will return $h_{id_i}$. Otherwise, $C$ will select a random $h_{id_i}$, stores $(id_i, h_{id_i}, S_{id_i})$ to $L_1$ and returns $h_{1i}$ to $\Gamma$.

$SC_\epsilon$ query: $\Gamma$ will execute a $SC_\epsilon$ query for $m_i$ with $id_A$ and $id_B$. If $id_A \neq id_j$, $C$ will first get a secret key for $id_A$ by querying $ET_\epsilon$ oracle, then $C$ will run $SC(id_A, S_{id_B}, sig)$ to answer $C$ 's query.

$US_\epsilon$ query: if $\Gamma$ queries a $(c, r, z)$ for $US_\epsilon$ query with $id_A$ and $id_B$. If $id_B \neq id_j$, $C$ will first obtain a secret key for $id_B$ by querying $EX_\epsilon$ oracle. After that, $C$ will return $US(c, r, z, id_A, S_{id_B})$ to answer $\Gamma$.

Challenge: After $\Gamma$ finishes a larger number of queries, $\Gamma$ will select $id_A^*$ and $id_B^*$, that he wants to be challenged. Then $\Gamma$ submits $m_0, m_1$ to $\Gamma$. $C$ will randomly choose $r^* \leftarrow \{0,1\}^*, z^* \leftarrow \{0,1\}^*$, and set $z^* = \tilde{z}$. At last, $C$ will return $\sigma^* = (c^*, r^*, z^*)$ to $\Gamma$.

Phase 2: After $\Gamma$ finishes a large number of queries adaptively as in former step. $id_B^*$ will not be queries in ET oracle, and $\sigma^*$ will not be queried in $US$ oracle.

Guess: $\Gamma$ will generate one $p^{'}$, which can be ignored by $C$. $C$ searches in $L$ for tuple $(r_i, AS_i, H_i)$. For each of them, $C$ will check whether $\tilde{z} = \tilde{A}S_i + y_i$ keeps. If it keeps , $C$ will stop and output $S_i$ as one solution of LWE problem. Otherwise, $C$ stops and outputs $false$.

Now we will need to analyze the success probability of $C$. We denote $E_H$ as the event that $\Gamma$ query the $H$ oracle during the simulation. So we can get$Pr[p^{'} = p] = 1/2 + 1/2Pr[E_H]$, then we can get $\epsilon = |2Pr[p^{'} = p] - 1| \leq Pr[E_H]$. Following the method of [Li et al., 2013], we can get $C$ can solve LWE problem with $\epsilon^{'} \geq \epsilon - q_H q_u/2^n$ in time $t^{'} < t + (q_u + q_H)t_H + q_u t_{H_2}$.

Theorem 2 (sUF-CMA) if one adversity $\Gamma$ can win sUF-CMA game with non-negligible probability $\varepsilon_{sc}$ in a time $t$ after $q_e$ times $ET_\epsilon$ queries, $q_s$ times $SC_\epsilon$ queries, $q_u$ times $US_\epsilon$ queries, and $q_{H_1}, q_{H_2}, q_H$ times queries respectively to oracles $H_1, H_2, H$, there is an algorithm $C$ who can solve SIS problem with probability at least $1/2(1 - 2^{-\omega(logn)})$.

Proof. assume a polynomial algorithm $C$ gets one instance of SIS $\tilde{A}x = 0$ mod q, his aim is to find a $x$ as $||x|| \leq (4\sigma + 2s\lambda)\sqrt{m}$. $C$ can run $\Gamma$ as its subprogram, and be a challenger for $\Gamma$.

$C$ initially runs $ST_\epsilon$ to generate $paras$. Then $\Gamma$ can execute a larger number of queries for oracle, $ET_\epsilon$ queries, $SC_\epsilon$ queries, and $US_\epsilon$ queries. $C$ will answer $\Gamma$'s queries. When receiving $Ay, H_1(id_R))$ query, $C$ answers as follows:

$C$ randomly chooses $s_{id}$ $(||s_{id}|| \leq s\sqrt{m+w})$, sets $Az - H_1(id_s)(A||r) = Ay$, $C$ stores $(m_i, r_i, y_i, h_{2i})$ to $L_2$, and returns $h_{2i}$ to $\Gamma$.

At last, if $C$ never aborts, $\Gamma$ will obtain one $sig^*$ on $m^*$, where $m^*$ has never been queried for $id_A^*, id_B^*$. Then $C$ can run $US_\epsilon$ for $sig^*$ and get $r^*, m^*$ by running $ET_\epsilon$ to obtain $id_B^*$'s secret key, which meets the requirements of $s_{id}^* \leq s\sqrt{m}$ and $(Az - H_1(id_S)r = Ay$. Before forging $sig^*$, $\Gamma$ queried $H_2$ for $m^*, r^*$. Thus, $C$ searches in $L_2$ for $m^*, r^*, s_{id_i}, h_{2_i}$, such that $(Az^* - H_1(id_S)r^*) = Ay$

if $id_A^* = id_j$, $C$ can obtains the following equation $A(z - z^* - S_{id_S}r + S_{id_S}r^*) = 0$. Due to $||z^*||, ||z|| \leq 2\sigma\sqrt{m}$ and by design $||S_{ID}r^*||, ||S_{ID}r|| \leq s\lambda\sqrt{m}$, we obtain $z - z^* - S_{id_S}r + S_{id_S}r^* \leq (4\sigma + 2s\lambda)\sqrt{m}$.

So we need to present $z - z^* - S_{id_S}r + S_{id_S}r^* \neq 0$ with non-negligible probability. By the preimage min-entropy property [Li et al., 2013], with probability no less than $(1 - 2^{-\omega(logn)})$. We can obtain another signing key $S_{id}$, $z - z^* - S_{id_S}r + S_{id_S}r^* \neq 0$ with probability at least $1/2$, so we can solve SIS problem with probability $1/2(1 - 2^{-\omega(logn)})$, we prove this theorem.

### 4.2 Performance

We now compare our IBSC's performance with Yan's scheme [Yan et al., 2013] and Li's scheme [Li et al., 2013]. From Table 1, we can see the SC speed of our scheme's is $O(1)$, it is the same with Li's scheme, it is faster than Yan's scheme. Our scheme's US speed is $O(1)$, it is faster than that of Yan's scheme. The user's secret key of our scheme is $mk \log q$, it is shorter than that of Yan's scheme and L's scheme. The security of Yan's scheme is proved in the standard model, our scheme and Li's scheme are secure in the random oracle (ROM). The performance comparison is given as below.

**Table 1:** Performance Comparison

| IBSC Scheme | [Yan et al., 2013] | [Li et al., 2013] | Our scheme |
|---|---|---|---|
| Hard Problem | LWR/LWE | LWE/ISIS | LWE/ SIS |
| SC speed | $O(n)$ | $O(1)$ | $O(1)$ |
| US speed | $O(n)$ | $O(1)$ | $O(1)$ |
| Size of secret key | $n^2 \log^2 q \log(\log n)$ | $mnl_q/m^2l_q$ | $mk \log q$ |
| Security model | Standard model | ROM | ROM |

## 5 Conclusions

In this paper, we design a lattice-based IBSC scheme by using rejection sampling theorem. Then we demonstrate our IBSC scheme is secure, i.e., it satisfies IND-CCA2 and sUF-CMA. After that, we compare our scheme's performance with other existing IBSC schemes, the results show that our scheme outperforms other schemes in terms of user's secret key, our scheme's SC speed and US speed are faster than that of Yan's scheme. In addition, Yan's scheme and Li's scheme are constructed based on trapdoor, our scheme does not need to rely on a trapdoor.

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