Attribute Revocable Attribute-Based Encryption with Forward Secrecy for Fine-Grained Access Control of Shared Data

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SUMMARY Ciphertext-Policy Attribute-Based Encryption (CP-ABE) is suitable for data access control on cloud storage systems. In ABE, to revoke users’ attributes, it is necessary to make them unable to decrypt ciphertexts. Some CP-ABE schemes for efficient attribute revocation have been proposed. However, they have not been shown to achieve fine-grained access control of shared data. We propose an attribute revocable attribute-based encryption with the forward secrecy for fine-grained access control of shared data. The proposed scheme can use both “AND” and “OR” policies and is IND-CPA secure under the Decisional Parallel Bilinear Diffie-Hellman Exponent assumption in the standard model.

key words: cryptographic cloud storage, ciphertext-policy attribute-based encryption, semantic security, attribute revocation, proxy re-encryption

1. Introduction

Sharing service on a cloud storage has a risk of information leakage caused by unauthorized access and service provider’s abuse. In order to prevent the risk, data owners encrypt sharing data on the cloud storage so that only authorized users can decrypt.

Ciphertext-policy attribute-based encryption (CP-ABE) [1], [2] is suitable for data access control of cloud storage systems. In CP-ABE, data owners choose an access structure and encrypt message under the access structure. The set of attributes assigned to users is embedded in his secret key. A user is able to decrypt ciphertexts if his attributes satisfy the access structure of ciphertexts.

In ABE, to revoke users’ attributes, it is necessary to make them unable to decrypt ciphertext. In simple user’s attribute revocation, when one’s attributes are revoked, a data owner re-encrypts shared data so that revoked user cannot decrypt. However, it is not realistic to re-encrypt all shared data.

Some attribute revocable CP-ABE schemes have been proposed [3]–[5]. In these schemes, the authority can revoke the only specified attributes.

In the scheme of [3], the authority can delegate re-encryption and secret key update to a proxy server by proxy re-encryption. When a user accesses encrypted shared data, the proxy server re-encrypts them. Although this scheme has been given a formal security proof against an unauthorized user with semi-trusted proxy servers, it has not been given a formal security proof against a revoked user.

In the scheme of [4], a service provider provides a data outsourcing service. It consists of data servers and a data service manager. Outsourced data from data owners are stored in the data servers. The data server manager distributes key encryption keys (KEKs) to each user. The data service manager re-encrypts a ciphertext by an attribute group key. Then, it encrypts the attribute group key by using KEKs so that authorized users can decrypt. The data service manager is assumed to be honest-but-curious. As the number of system users has increases, the number of KEKs also increases and the management of KEKs becomes more complicated. This scheme also has not been given a formal security proof against a revoked user.

In the scheme of [5], any user cannot decrypt a ciphertext encrypted by a public key the authority generated. When a user downloads encrypted sharing data from the cloud server, the cloud server re-encrypts it by proxy re-encryption so that the user can decrypt it. When revoked user downloads encrypted sharing data, the cloud server does not re-encrypt it, so revoked user cannot decrypt it. This scheme has a limitation in access policy because it only supports “AND” policy.

In this paper, we propose an attribute revocable attribute-based encryption with the forward secrecy for fine-grained access control of shared data. In the context of attribute-based encryption, the forward secrecy means that any user whose attributes were revoked should be prevented from accessing the plaintext of data after revocation, unless other valid attributes he holds satisfy the access policy [4]. In the proposed scheme, it is possible to use not only “AND” but also “OR” for an access policy and the authority can revoke the only specified user’s attribute. Furthermore, the proposed scheme meets the following security requirements in [3]–[5] besides the forward secrecy.

1. Data confidentiality: Unauthorized users who do not have enough attributes satisfying the access policy and the cloud server should be prevented from accessing the plaintext of the data.
2. Collusion-resistance: If multiple unauthorized users...
and the cloud server collude, when they do not have enough attributes satisfying the access policy, they cannot decrypt a ciphertext.

We define attack model 1 as an attack by unauthorized users and the cloud server. Moreover, we define attack model 2 as an attack by a revoked user. We prove the proposed scheme is IND-CPA secure against attacks defined in each attack model under the Decisional Parallel Bilinear Diffie-Hellman Exponent (DPBDHE) assumption in the standard model.

2. Preliminaries

2.1 Bilinear Maps

Let $G_1, G_2$ be two cyclic groups of a prime order $p$. Let $g$ be a generator of $G_1$. A bilinear map is a map $e: G_1 \times G_1 \rightarrow G_2$ with the following properties:

1. Bilinearity: for all $u, v \in G_1$ and $a, b \in \mathbb{Z}_p$, we have $e(u^a, v^b) = e(u, v)^{ab}$
2. Non-degeneracy: $e(g, g) \neq 1$
3. Computability: There is an efficient algorithm to compute $e(u, v)$ for all $u, v \in G_1$

2.2 Decisional Parallel Bilinear Diffie-Hellman Exponent (DPBDHE) Assumption

In [2], the Decisional q-Parallel Bilinear Diffie-Hellman Exponent defined as follows. Choose a group $G_1$ of prime order $p$ according to the security parameter. Let $a, b_1, \ldots, b_l \in \mathbb{Z}_p$ be chosen at random and $g \in G_1$ be a generator of $G_1$. An adversary is given $\vec{y} = g^{b_1}, g^{b_2}, \ldots, g^{b_l}, g^{a \cdot b_1}, \ldots, g^{a \cdot b_l}$.

It must remain hard to distinguish $e(g, g)^{a \cdot b} \in G_2$ from a random element in $R \in G_2$.

An algorithm $\mathcal{A}$ that outputs $z \in \{0, 1\}$ has advantage $\epsilon$ in solving decisional q-parallel BDHE in $G_1$ if

$$\Pr[\mathcal{A}(\vec{y}, T = e(g, g)^{a \cdot b}) = 0] - \Pr[\mathcal{A}(\vec{y}, T = R) = 0] \geq \epsilon$$

We say that the (decision) q-parallel-BDHE assumption holds if no polytime algorithm has a non-negligible advantage in solving the decisional q-parallel BDHE problem.

2.3 Access Structure [6]

Let $\{P_1, P_2, \ldots, P_n\}$ be the set of parties. A collection $\mathcal{A} \subseteq 2^{P_1 \cup P_2 \cup \ldots \cup P_n}$ is monotone if $V \subseteq B, C$: if $B \in \mathcal{A}$ and $B \subseteq C$ then $C \in \mathcal{A}$. An access structure (respectively, monotone access structure) is a collection (respectively, monotone collection) $\mathcal{A}$ of nonempty subsets of $\{P_1, P_2, \ldots, P_n\}$, i.e., $\mathcal{A} \subseteq 2^{P_1 \cup P_2 \cup \ldots \cup P_n} \setminus \{\emptyset\}$. The sets in $\mathcal{A}$ are called the authorized sets, and the sets not in $\mathcal{A}$ are called the unauthorized sets.

In our context, the role of the parties is defined by attributes. An access structure $\mathcal{A}$ contains the authorized sets of attributes. Unless otherwise stated, by an access structure we mean a monotone access structure.

2.4 Linear Secret Sharing Schemes (LSSS)

Definition 1 (Linear Secret Sharing Schemes (LSSS) [2, 6])

As shown in [6], any LSSS defined as above enjoys the linear reconstruction property defined as follows. A secret-sharing scheme $\Pi$ over a set of parties $P$ is called linear (over $\mathbb{Z}_p$) if

1. The shares for each party form a vector over $\mathbb{Z}_p$.
2. There exists a matrix $M$ with $l$ rows and $n$ columns called the share-generating matrix for $\Pi$. For all $i = 1, \ldots, l$, the $i$’th row of $M$ we let the function $\rho$ defined the party labeling row $i$ as $\rho(i)$. When we consider the column vector $v = (s, r_2, \ldots, r_n)$, where $s \in \mathbb{Z}_p$ is the secret to be shared, and $r_2, \ldots, r_n \in \mathbb{Z}_p$ are randomly chosen, then $Mv$ is the vector of $l$ shares of the secret $s$ according to $\Pi$. The share $(Mv)_i$ belongs to the party $\rho(i)$.

Suppose that $\Pi$ is an LSSS for the access structure $\mathcal{A}$. Let $S \in \mathcal{A}$ be any authorized set, and let $I \in \{1, 2, \ldots, l\}$. Then, there exist constants $\omega_i \in \mathbb{Z}_p$ such that, if $\{\lambda_i\}$ are valid shares of any secret $s$ according to $\Pi$, then $\sum_{i \in \mathcal{A}} \omega_i \lambda_i = s$. Furthermore, these constants $\{\omega_i\}$ can be found in polynomial time in the size of the share-generating matrix $M$ [6].

3. System Model and Definition

3.1 Entities

There are four entities in the proposed scheme as follows.

User: Users downloads shared data from the cloud server.

Data Owner: Data owners encrypt shared data then uploads them to the cloud Server.

Authority: The authority manages attributes in the system and publishes the parameter used for encryption. It generates a secret key that user’s attributes are embedded in and the re-encryption key used for re-encryption and updates a secret key. The authority is a trusted party.

Cloud Server: The cloud server stores shared data. It re-encrypts encrypted shared data and updates a secret key by using the re-encryption key received from the authority. Similar to the previous scheme [5], we assume cloud servers to be honest-but-curious. That is, they will honestly execute the tasks assigned by legitimate parties in the system. However, they would like to learn information of encrypted shared data as much as possible.

In the previous scheme [4], when an attribute revocation event occurs, a semi-trusted proxy server which is deployed in data server re-encrypts data by using proxy rekey and updates a component of secret key by using it. In
the proposed scheme, when a user accesses data after an attribute revocation event, Cloud Server re-encrypts data by using re-encryption key. Both entities do not have secret key, then they cannot decrypt encrypted data. From the above, our storage is similar in trust model to the proxy server in [4], if the proxy server re-encrypts data and updates keys at the timing of user’s access after attribute revocation events.

3.2 Algorithm Definition

-Auth.Setup: The setup algorithm takes as input the security parameter $\lambda$ which represents encryption strength and attribute universe description $U$ which represents the number of system attributes. It outputs the public parameter $PK$, the master secret key $MK$ and the re-encryption key $RK$.
-Auth.Ext: The key extraction algorithm takes as input the master key $MK$, and a set of attributes $S$. It outputs the secret key $SK$.
-DO.Enc: The encryption algorithm takes as input the public parameter $PK$, an access structure $A$ and a message $M$. It outputs the ciphertext $CT$.
-C.ReEnc: The re-encryption algorithm takes as input a ciphertext $CT'$, a set of attributes $S$ and the re-encryption key $RK$. It outputs the re-encryption ciphertext $CT$.
-U.Dec: The decryption algorithm takes as input the secret key $SK$ for a set $S$ and the ciphertext $CT$ for an access structure $A$. If the set of attributes $S$ satisfies the access structure $A$, it outputs the message $M$.

3.3 Security Definitions

We prove that unauthorized users, the cloud server and revoked users cannot decrypt ciphertext encrypted by the proposed scheme. We define the attack model 1 as an attack by unauthorized users and the cloud server. Moreover, we define the attack model 2 as an attack by a revoked user. The cloud server would like to learn information of encrypted shared data as much as possible, but we assume the cloud server is honest, we do not consider active attacks from it by colluding with revoked users as in [3]–[5]. We prove the proposed scheme is IND-CPA secure against attack models and show that the proposed scheme satisfies data confidentiality, collusion-resistance and forward secrecy. In our security model, the adversary will choose to be challenged on an encryption to an access structure $A^*$ which is called the challenge access structure and can ask for any secret key $SK$ such that $SK$ does not satisfy $A^*$.

3.3.1 Attack Model 1

In this model, we assume an attack by unauthorized users and the cloud server. Security in this model is defined with the following game.

Init. The adversary $A$ submits the challenge access structure $A^*$ to the challenger $C$.
Setup. The challenger $C$ runs setup algorithm and gives the public parameter $PK$ and the re-encryption key $RK$ to the adversary $A$.
Phase1. The adversary $A$ can issue the following query.
Ext query: The adversary $A$ submits a set of attributes $S$ where $S$ does not satisfy the access structure $A^*$ to the challenger $C$. The challenger $C$ gives the secret key $SK$ corresponding to $S$.
Challenge. The adversary $A$ submits two equal length messages $M_0, M_1$. The challenger $C$ flips a random coin $b$. Next, the challenger $C$ encrypts $M_b$ under $A$ and computes the ciphertext $CT^*$. Then, the challenger $C$ runs re-encryption algorithm and gives the re-encryption ciphertext $CT^*$ to the adversary $A$.
Phase2. Phase1 is repeated.
Guess. The adversary $A$ outputs his guess $b'$ of $b$.
The advantage of an adversary $A$ in this game is defined as
$$\Pr[b' = b] - \frac{1}{2}.$$A ciphertext-policy attribute-based encryption scheme is IND-CPA secure in this model if all polynomial time adversaries have at most a negligible advantage in the above game.

3.3.2 Attack Model 2

In this model, we assume an attack by a revoked user. Security in this model is defined with the following game.

Init. The adversary $A$ submits the challenge access structure $A^*$ and a revoked attribute $x^*$ where $x^* \in A^*$ to the challenger $C$.
Setup. The challenger $C$ runs setup algorithm and gives the public parameter $PK$ to the adversary $A$.
Phase1. The adversary $A$ can issue the following query.
Ext query: The adversary $A$ submits a set of attributes $S$ where $S$ does not satisfy the access structure $A^*$ and $x^* \in S$ to the challenger $C$. The challenger $C$ gives the secret key $SK$ corresponding to $S$.
Challenge. The adversary $A$ submits two equal length messages $M_0, M_1$. The challenger $C$ flips a random coin $b$. Next, the challenger $C$ encrypts $M_b$ under $A$ and computes the ciphertext $CT^*$. Then, the challenger $C$ runs re-encryption algorithm and gives the re-encryption ciphertext $CT^*$ to the adversary $A$.
Phase2. Phase1 is repeated.
Guess. The adversary $A$ outputs his guess $b'$ of $b$.
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4. Our Scheme

4.1 Overview

The proposed scheme is based on Water’s scheme of CP-ABE [2]. It is proved that Waters’s scheme is IND-CPA secure under the DBDHE assumption. Moreover, Water’s scheme supports any LSSS access structure, so it is possible to use “AND” and “OR” for an access policy.

In the proposed scheme, any user cannot decrypt a ciphertext encrypted by a public key the authority generated. When a user downloads an encrypted sharing data from the cloud server, the server re-encrypts it by proxy re-encryption so that the user can decrypt it. When a revoked user downloads encrypted sharing data, the cloud server doesn’t re-encrypt it, so the revoked user cannot decrypt it [5].

4.2 Algorithm

-Auth.Setup: The setup algorithm takes as input the number of system attributes $U$. It first chooses a group $G_1$ of prime order $p$, a generator $g \in G_1$. Then it chooses a random $\alpha, a, f_1, \ldots, f_U, d_1, \ldots, d_U \in \mathbb{Z}_p$. The public parameters are $PK := (g, g^a, g^\alpha, F_1 := g^{f_1}, \ldots, F_U)$. The master key is $MK := \alpha$. The re-encryption key is $RK := (r_k := d_1/f_1, \ldots, r_k) := d_1/f_2$.

-Auth.Ext: The key extraction algorithm takes as input the master key $MK$, and a set of attributes $S$. It first chooses a random $t \in \mathbb{Z}_p$. Then it outputs secret key $SK := (K, L, (K_x | x \in S) = (g^\alpha g^{s_x}, g^{|t|}, (d_x) | x \in S))$.

-DO.Enc: The encryption algorithm takes as input the public parameter $PK$, an LSSS access structure $(M, \rho)$, and a message $M$. The function $\rho$ associates rows of $M$ to attributes. Let $L$ be an $l \times n$ matrix. It first chooses a random vector $\vec{v} = (s_1, s_2, \ldots, s_n) \in \mathbb{Z}_p$. For $i = 1$ to $l$, it computes $A_i := \vec{v} \cdot M_i$. It then chooses random $r_1, \ldots, r_l \in \mathbb{Z}_p$ and outputs the ciphertext

$$CT := (C', C, (C_i, D_i), \ldots, (C_i, D_i)) = \langle Ke(g, g^a)^{\alpha \vec{v}_i}, (g^\alpha \rho F^{\rho}(D_i), g^{|t_i|}), \ldots, (g^{\alpha \rho} F^{\rho}(D_i), g^{|t_i|}) \rangle$$

with $(M, \rho)$.

-C.ReEnc: The re-encryption algorithm takes as input a ciphertext $CT'$, a set of attribute $S$ and re-encryption key $RK$. Let $M$ be an $l \times n$ matrix. For $i = 1$ to $l$, if $\rho(i) \in S$, the re-encryption algorithm computes

$$D_i := (D_i)^{-r_k} = g^{r_k/l_i}.$$ 

If $\rho(i) \notin S, D_i := D_i'$. It outputs re-encrypted ciphertext $CT := ((M, \rho), C, C', (C_i, D_i), \ldots, (C_i, D_i))$.

-U.Dec: The decryption algorithm takes as input a secret key $SK$ for a set $S$ and a re-encrypted ciphertext $CT$ for an access structure $(M, \rho)$. Suppose that $S$ satisfies the access structure and let $I$ be defined as $I = \{i : \rho(i) \in S\}$. Then, let $\omega_i \in \mathbb{Z}_p$ be as set of constants such that if $\{A_i\}$ are valid shares of the secret $s$ according to $M$, then

$$\sum_{i \in I} \omega_i.A_i = s.$$ The decryption algorithm first computes

$$e(C', K) \cdot \prod_{i \in I} e(C_i, L) e(D_i, K_{\rho(i)})^{\omega_i} = e(g, g)^{\alpha \vec{v}_i} \cdot e(g, g)^{\alpha \vec{v}_i} \cdot K_{\rho(i)}^{\omega_i} = e(g, g)^{\alpha \vec{v}_i}.$$ 

It can then decrypt the message $M = C/.g^\alpha$.

We show the flow of our scheme in Fig. 1.

4.3 Attribute Revocation Procedure

The attribute revocation is done by the following procedure:

1. An authority sends the user’s revoked attitude $\theta \subseteq S$ to a cloud server.
2. A cloud server updates the attribute set of the user based on the revocation message.
3. When the user accesses the data in the cloud server, the cloud server runs re-encryption algorithm in accordance with an updated attribute set of the user, and sends the re-encrypted ciphertext to the user.

5. Security Proof

We prove that unauthorized users and the cloud server and revoked user cannot decrypt ciphertext $CT$ that was encrypted by using the proposed scheme.

5.1 Security Proof in the Attack Model 1

**Theorem 1** Suppose the decisional q-parallel BDHE assumption holds and a challenge matrix of size is $l \times n$ where $l \times n \leq q$, our scheme is IND-CPA secure in the attack model 1.

**Proof** Suppose we have adversary $A$ with non-negligible advantage $\epsilon$ against our scheme in the attack model 1. Moreover, suppose it chooses a challenge matrix $M'$ where both dimensions are at most $q$. We show how to build a simulator, $B$, that plays the decisional q-parallel
BDHE problem.

Init. The simulator takes in a q-parallel BDHE challenge $\bar{y}$, $T$. The adversary gives the simulator $B$ the challenge access structure $(M^*, \rho^*)$, where $M^*$ has $n^*$ columns.

Setup. The simulator $B$ generates the public parameter $PK$ as follows. The simulator $B$ chooses random $\alpha' \in \mathbb{Z}_p$ and implicitly sets $\alpha = \alpha' + \alpha^{q+1}$ by letting $e(g, g)^\alpha = e(g, g)^{\alpha'} = e(g^\alpha, g^{\alpha'})e(g, g)^{\alpha'}$. For each $x$ for $1 \leq x \leq U$ begin by choosing a random value $z_x$. Let $X$ denote the set of indices $i$, such that $\rho^*(i) = x$. The simulator $B$ programs $F_x$ as

$$F_x = g^x \prod_{i \in X} g^{\alpha M^*_i/b_i} \cdot g^{\alpha^2 M^*_i/b_i} \cdots g^{\alpha^n M^*_i/b_i}$$

Note that if $X = \emptyset$ then we have $F_x = g^{\bar{y}}$. The simulator $B$ gives the adversary $A$ the public parameter $PK := (g, e(g, g)^\alpha, e^i, \ldots, F_U)$.

Phase 1. The adversary $A$ issues the following query:

Ext query: The adversary $A$ submits a set of attributes $S$ where $S$ does not satisfy the access structure $M^*$ to the challenger. The simulator first chooses a random $r, r_1, \ldots, r_{|U|} \in \mathbb{Z}_p$. Then it finds a vector $\bar{w} = (w_1, \ldots, w_{|U|}) \in \mathbb{Z}_p^{n^*}$ such that $w_1 = -1$ and for all $i$ where $\rho(i) \in S$ we have that $\bar{w} \cdot M^*_i = 0$.

The simulator $B$ begins by implicitly defining $t$ as

$$r + w_1 q^\alpha + w_2 q^{\alpha+1} + \cdots + w_{|U|} q^{\alpha n^* + 1}$$

It performs this by setting $L = g^t \prod_{i=2}^{n^*} (g^{q^{\alpha+i-1}})^{w_i}$. The simulator can compute $K$ as

$$K = g^{\alpha^i} \prod_{i=2}^{n^*} \left( g^{q^{\alpha+i-1}} \right)^{w_i}$$

The simulator $B$ computes $\{K_i | x \in S\}$ as follows. If there is no $i$ such that $\rho^*(i) = x$, it computes $K_x = L^{x} r^{s_k}$. If there is $i$ such that $\rho^*(i) = x$, let $X$ be the set of all $i$ such that $\rho^*(i) = x$. The simulator $B$ computes $K'_x$ as

$$L^{x} \prod_{i=1}^{n^*} \prod_{j=1}^{n^*} \left( g^{q^{\alpha+i+j-1}} \right)^{w_{i,j}}$$

and computes $K_x = (K'_x)^{s_k}$.

It gives the adversary $A$ secret key $SK := (K, L, \{K_i \mid x \in S\})$.

Challenge. The adversary $A$ submits two equal length messages $M_0, M_1$. The simulator $B$ flips a random coin $b \in \{0, 1\}$. It computes $C = M_{b} T \cdot e(g^x, g^{\alpha^x})$, $C = sP$.

It chooses random $y_1', \ldots, y_{|U|}' \in \mathbb{Z}_p$ and the shares of the secret using the vector $\bar{y}' = (s, sa + y_2', sa^2 + y_3', \ldots, sa^{n-1} + y_{|U|}') \in \mathbb{Z}_p^{n^*}$ in addition, it chooses random values $r_1', \ldots, r_{|U|}' \in \mathbb{Z}_p$. For $i = 1, \ldots, n^*$, we define $R_i$ as the set of all $k \neq i$ such that $\rho^*(i) = \rho^*(k)$. The challenge ciphertext components are then generated as

$$D'_i = g^{r'_i} g^{-s_k b_i}$$

$$C_i = K''_{r(i)} \left( \prod_{j=1}^{n^*} (g^{\alpha^i M^*_j}) \right) (g^{b_i} e^{\frac{y_i}{q^\alpha}})$$

$$\left( \prod_{k \in R_i} \prod_{j=1}^{n^*} (g^{\alpha^i q(\alpha b_i b_j)}) \right)$$

Phase 2. Phase 1 is repeated.

Guess. The adversary $A$ will eventually output a guess $b'$ of $b$. The simulator $B$ then outputs 0 to guess that $T = e(g, g)^{\alpha q + x}$ if $b' = b$; otherwise, it outputs 1 to indicate that it believes $T$ is a random group element $R \in G_2$. When $T$ is a tuple, the simulator $B$ gives a perfect simulation, so we have that

$$\Pr[\bar{y}, T = e(g, g)^{\alpha q + x}] = 0 = \frac{1}{2} + \epsilon.$$

When $T$ is a random group element, the message $M_b$ is completely hidden from the adversary and we have $\Pr = [B(\bar{y}, T = R) = 0] = \frac{1}{2}$. Therefore, the simulator $B$ can play the decisional q-parallel BDHE game with non-negligible advantage.

5.2 Security Proof in the Attack Model 2

Theorem 1 Suppose the decisional q-parallel BDHE assumption holds and a challenge matrix whose size is $l' \times n'$ where $l' \times n' \leq q$, our scheme is IND-CPA secure in the attack model 2.

Proof Suppose we have an adversary $A$ with non-negligible advantage $\epsilon$ against our scheme in the attack model 2. Moreover, suppose it chooses a challenge matrix $M^*$ where both dimensions are at most $q$. We show how to build a simulator $B$ that plays the decisional q-parallel BDHE problem.

Init. The simulator takes in a q-parallel BDHE challenge $\bar{y}, T$. The adversary gives the simulator $B$ the challenge access structure $(M^*, \rho^*)$ and $x^*$, where $M^*$ has $n^*$ columns and there must exist $i$ such that $\rho^*(i) = x^*$.

Setup. The simulator $B$ generates the public parameter $PK$ as follows. The simulator $B$ chooses random $\alpha' \in \mathbb{Z}_p$ and implicitly sets $\alpha = \alpha' + \alpha^{q+1}$ by letting $e(g, g)^\alpha = e(g, g)^{\alpha'} = e(g^\alpha, g^{\alpha'})e(g, g)^{\alpha'}$. For each $x \neq x^*$ for $1 \leq x \leq U$ begin by choosing random values $z_x$, $r_{k \in R_i} \in \mathbb{Z}_p$. Let $X$ denote the set of indices $i$, such that $\rho^*(i) = x$. The simulator $B$ programs $F_x$ as

$$F_x = g^{\bar{y}} \prod_{i \in X} g^{\alpha M^*_i/b_i} \cdot g^{\alpha^2 M^*_i/b_i} \cdots g^{\alpha^n M^*_i/b_i}$$

Note that if $X = \emptyset$ then we have $F_x = g^{\bar{y}}$. For the revoked attribute $x^*$, it chooses a random $z_{x^*} \in \mathbb{Z}_p$. Let $X^*$ denote the set of indices $i$, such that $\rho^*(i) = x^*$. It computes $r_{k \in R_i}$ as

$$r_{k \in R_i} = z_{x^*} / (z_{x^*} + (aM_{i,j}^{(l-1)}/b_i) + (a^2 M_{i,j}^{(l-2)}/b_i) + \cdots + (a^n M_{i,j,l}/b_i)).$$
The simulator $B$ gives the adversary $A$ the public parameter $PK := (g, e(g, g)^x, g^a, F_1, \ldots, F_U)$.

**Phase 1.** The adversary $A$ issues the following query:

**Ext query:** The adversary $A$ submits a set of attributes $S$ where $S - x^*$ does not satisfy the access structure $M^*$ and $x^* \in S$ to the challenger. Then it finds a vector $\vec{w} = (w_1, \ldots, w_n) \in \mathbb{Z}_p^*$ such that $w_i = -1$ and for all $i$ where $p(i) \in S$ we have that $\vec{w} \cdot M_i^* = 0$.

The simulator $B$ begins by implicitly defining $t$ as

$$r + w_1 a^0 + w_2 a^{q_1} + \cdots + w_p a^{q_p} + 1$$

It performs this by setting $L = g^{q_i(t)} \prod_{i=2}^{n} (g^{a^{q_i(t)}/q_i})^{w_i}$.

The simulator $B$ computes $\{K_i | x \in S\}$ as follows. If there is no $i$ such that $\rho(i) = x$, it computes $K_i = L_z^{K_i}$. If there is $i$ such that $\rho(i) = x$, let $X$ be the set of all $i$ such that $\rho(i) = x$. The simulator $B$ computes $K_i$ as follows.

If $x = x^*$, it defines $K^*_x$ as

$$L_z^{K^*_x} \prod_{i=1}^{n} \prod_{j=1}^{m^*} \left( g^{a^{q_i/b_i}s_j} \prod_{k=1}^{k_{x,j}} (g^{a^{q_i+b_i}/b_i})^{w_k} \right)^{M_{x,j}^*}$$

and computes

$$K_i = L_z^{K^*_x} \prod_{i=1}^{n} \prod_{j=1}^{m^*} \left( g^{a^{q_i/b_i}s_j} \prod_{k=1}^{k_{x,j}} (g^{a^{q_i+b_i}/b_i})^{w_k} \right)^{M_{x,j}^*}$$

and

$$K_i = (K_i)^{K_i^*}$$

It gives the adversary $A$ secret key $SK := (K, L, \{K_i | x \in S\})$.

**Challenge.** The adversary $A$ submits two equal length messages $M_b, M_t$. The simulator $B$ flips a random coin $b \in \{0, 1\}$. It computes $C = M_b T \cdot e(g^x, g^a^x), C = sP$. It chooses random $y_2', \ldots, y_n' \in \mathbb{Z}_p$ and the shares of the secret using the vector $\vec{v} = (s, sa + y_2', sa^2 + y_3', \ldots, sa^{q_p} + y_n') \in \mathbb{Z}_p^*$. In addition, it chooses random values $r_1', \ldots, r_l' \in \mathbb{Z}_p$. For $l = 1, \ldots, n'$, we define $R_l$ as the set of all $k \neq i$ such that $\rho^*(i) = \rho^*(k)$. The challenge ciphertext components are then generated as

$$C_t = h^{y_2'}_{p^*} \left( \prod_{j=2}^{n'} (g^{a^{q_j}})_{M_b}^{y_j} \right) (g^{bT})^{-Z_{p^*}}$$

If $\rho^*(i) = x^*$,

$$D_t = -r_i T_{r^*(i)} - s b_i T_{r^*(i)}$$

If $\rho^*(i) \neq x^*$,

$$D_t' = -r_i T_{r^*(i)} - s b_i T_{r^*(i)}$$

$$D_t = 1/r k_{\rho^*(i)} (D_t')$$

**Phase 2.** Phase 1 is repeated.

**Guess.** The adversary $A$ will eventually output a guess $b'$ of $b$. The simulator then outputs $0$ to guess that $T = e(g, g)^{a^{q_p}x}$ if $b' = b$; otherwise, it outputs $1$ to indicate that it believes $T$ is a random group element $R \in G_2$.

When $T$ is a tuple, the simulator $B$ gives a perfect simulation, so we have that

$$Pr = \frac{1}{2} + \epsilon.$$
smaller one. That is, when attribute revocation occurs frequently, as to the amount of computation of the cloud server, the proposed scheme and [5] have the equally smallest one.

As for the security, the proposed scheme and the scheme of [5] have been shown that they are IND-CPA secure against an attack by unauthorized users, the cloud server, and a revoked user.

7. Conclusion

This paper proposed an attribute revocable attribute-based encryption with the forward secrecy for fine-grained access control of shared data. In the proposed scheme, it is possible to use not only “AND” but also “OR” for an access policy and the authority can revoke the only specified user’s attributes. We proved the proposed scheme is IND-CPA secure against attacks defined as attack models under the Decisional Parallel Bilinear Diffie-Hellman Exponent (DPBDHE) assumption in the standard model, and show that the proposed scheme satisfies data confidentiality, collusion-resistance and forward secrecy.

Our future direction is to implement the proposed scheme and confirm its feasibility.

Acknowledgments

This work was supported by JSPS KAKENHI Grant Number 16K00184.

References


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