# Large Universe Ciphertext-Policy Attribute-Based Encryption with White-Box Traceability

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Accepted by the 19th European Symposium on Research in Computer Security (ESORICS) 2014

# Outline

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# Introduction: What is CP-ABE?

- CP-ABE is a tool for implementing fine-grained access control over encrypted data, and is conceptually closer to traditional access control methods such as Role-Based Access Control.
- A user is described by a set of descriptive attributes, and a corresponding private key is issued by an authority according to the attributes the user possess.
- During encryption, an encryptor associates an access policy over attributes with the ciphertext.
- A user will only be able to decrypt a ciphertext if that user's attributes pass through the ciphertext's access structure.

# Introduction: What is CP-ABE?

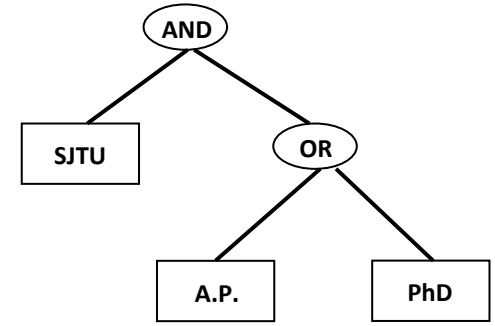
$PK$

$PK{\downarrow}SJTU$, $PK{\downarrow}THU$, …
$PK{\downarrow}CS$, $PK{\downarrow}EE$, …
$PK{\downarrow}A.P.$, $PK{\downarrow}PhD$, …
$PK{\downarrow}M$, $PK{\downarrow}F$, …
……
…..

$MSK$

Univ.: SJTU, THU, …
Dept.: CS, EE, …
Type: Assi. Prof., PhD Stud., …
Gender: Male, Female
……
……

$C=Enc(PK,\mathcal{P},M)$




$\mathcal{P}=SJTU\ AND\ (A.P.\ OR\ PhD)$

Storage Server
(Untrusted)

$SK{\downarrow}S{\downarrow}A$

$S{\downarrow}A$ satisfies $\mathcal{P}$

$S{\downarrow}A=\{SJTU, PhD\}$

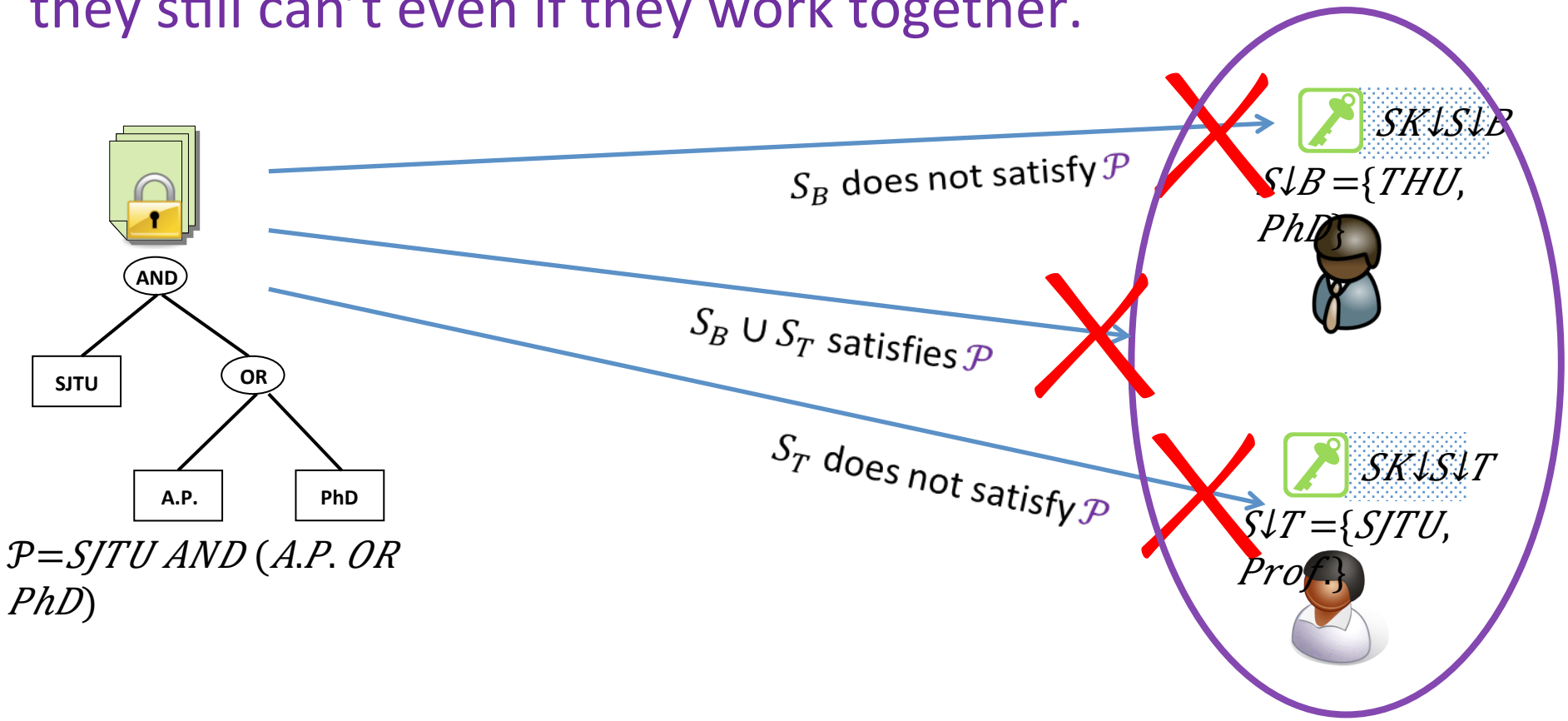
$S{\downarrow}B$ does not satisfy $\mathcal{P}$

$S{\downarrow}B=\{THU, PhD\}$

$SK{\downarrow}S{\downarrow}B$

# Introduction: What is CP-ABE?
# -- Collusion-resistant

If none of the users can decrypt a ciphertext individually, they still can't even if they work together.



# Introduction: What is CP-ABE? -- Definition

- $Setup(1\lambda, U) \longrightarrow pp, msk.$
- $Encrypt(1\lambda, pp, \mathcal{P}, m) \longrightarrow ct.$ $\mathcal{P}$ is implicitly included in $ct.$
- $KeyGen(1\lambda, pp, msk, S) \longrightarrow SK{\downarrow}S$ .
- $Decrypt(1\lambda, pp, SK{\downarrow}S, ct) \longrightarrow m$ $or \perp$. If and only if $S$ satisfies $\mathcal{P}$, $m$ can be recovered.

# Introduction: Why needs T-LU-CP-ABE? -- A Motivating Story

- ✓ Consider a commercial application such as a pay-TV system with huge number of users
  - ❖ Each user is labeled lots of related attributes (which are defined as the TV channels that the user have ordered).
  - ❖ Those who have paid for the TV channels could satisfy the access policy to decrypt the ciphertext and enjoy the ordered TV channels.

- ✓ There appears two problems as following
  - ❖ If someone buys the decryption key from the Internet at a lower cost, she/he could get access to the TV channels. Then who is selling the decryption key?
  - ❖ As the TV channels expand, an increasing number of new attributes need to be added. If the number of the attributes exceeds the bound set during the initial deployment of the pay-TV system, then the entire system has to be re-deployed and possibly all its data have to be re-encrypted.

# Introduction: Why needs T-LU-CP-ABE? -- Analysis

- ✓ Due to the nature of CP-ABE, it is difficult to find out the original key owner from an exposed key since the decryption key is shared by multiple users who have the same attributes
  - ❖ It is necessary f… e malicious users who intentionally le… tion keys.

traceability is required !

- ✓ In previous CP-ABE constructions, the attributes are fixed at system setup and the number of the attributes are bounded
  - ❖ If the bound is not specified large enough, the attributes may exhaust.
  - ❖ If the bound is … e the storage and communicatio… e to the corresponding increase of the …
  - ❖ Thus, it is necessary for the pay-TV system to support flexible number of attributes.

large universe is required !

# Related Work: Existing ABE Schemes

- ✓ Sahai et al. [SW05]: introduce ABE, but only for "threshold policies".
- ✓ Goyal et al. [GPSW06]: the CP-ABE notion.
- ✓ Bethencourt et al. [BSW07] : The first CP-ABE scheme.
- ✓ … …
- ✓ Many advances have been made for ABE as the following directions:
  - ❖ New proof techniques to obtain fully secure [LW10,OT10,LOSTW10,LW12];
  - ❖ Decentralizing trust by setting multiple authorities [Chase07, CC09, LW11];
  - ❖ Outsourcing computation [PRV12, GHW11];
  - ❖ … …

# Related Work: Existing LU-CP-ABE and T-CP-ABE

- ✓ Existing LU-CP-ABE directions:
  - ❖ Lewko and Waters [LW10a]: the first large universe KP-ABE construction built on composite order groups
  - ❖ Lewko [Lewko12] : the first large universe KP-ABE construction built on prime order groups
  - ❖ Rouselakis and Waters [RW13]: the first large universe CP-ABE construction built on prime order groups

- ✓ Existing T-CP-ABE directions:
  - ❖ Li et al. [LRK09]: the first notion of accountable CP-ABE to prevent illegal key sharing among colluding users
  - ❖ Li et al. [LHCCX11]: multi-authority ciphertext-policy (AND gates with wildcard) ABE scheme with accountability
  - ❖ Liu et al. [LCW13a]: white-box traceability CP-ABE
  - ❖ Liu et al. [LCW13b]: black-box traceability CP-ABE

# Motivation

To solve the obstacles of CP-ABE implementation in the commercial applications such as pay-TV systems and social networks:

- To trace the malicious users who intentionally leak their decryption keys, to prevent ( such as the pay-TV company) suffering from severe financial loss
- To realize large universe construction, i.e., to support flexible number of attributes (for such as the pay-TV company)
- To achieve the storage for traceability being at a constant level in the ideal case

# Our Results

We constructed a large universe CP-ABE system which is white-box traceable on prime order bilinear groups .

- We
- W
- W
- Th

The first practical CP-ABE system that supports :

white-box traceability

large universe

constant storage for tracing

# Our Results

| | LRK09 | LHCCX11 | LCW13 | RW13 | Ours |
|---|---|---|---|---|---|
| Large Universe | ✗ | ✗ | ✗ | ✓ | ✓ |
| Traceability | ✓ | ✓ | ✓ | ✗ | ✓ |
| Constant Storage for Tracing | ✓ | ✗ | ✗ | ⊘ | ✓ |
| Supporting Any Monotone Access Structures | ✗ | ✗ | ✓ | ✓ | ✓ |
| Constructed on Prime Order Groups | ✓ | ✗ | ✗ | ✓ | ✓ |
| Standard Model | ✗ | ✓ | ✓ | ✓ | ✓ |

The rest of this presentation…

1. Our construction
2. Extensions
3. Future Work

# Our T-LU-CP-ABE System : Abstract

- $Setup(1\lambda)\rightarrow pp,msk.$

  $pp$:$GD,g,u,h,w,v,\ g\uparrow\alpha\ ,e(g,g)\uparrow\alpha\ ;\ msk$:$\alpha,a,k\downarrow 1\ \ ,k\downarrow 2$

  - $k\downarrow 1\ \ ,k\downarrow 2$ are keys for probabilistic encryption scheme ($Enc,Dec$). Also, initializes an instance of Shamir's threshold scheme.

- $KeyGen(1\lambda,pp,msk,id,S=(A\downarrow 1\ ,A\downarrow 2\ ,\ldots,A\downarrow k\ ))\rightarrow sk\downarrow id,S=(K,K\uparrow'\ ,L,\ L\uparrow'\ ,\{K\downarrow\tau,1\ ,$ $K\downarrow\tau,2\ \}\downarrow\tau\in[k]\ )$.

  $K=g\uparrow\alpha/(a+c)\ w\uparrow r\ ,\ K\uparrow'=c\{K\downarrow\tau,2$ $(a$

  - $x=Enc\downarrow k\downarrow 1\ \ (id),\ y=f(x),c=Enc\downarrow k\downarrow 2\ \ (x||y)$.

- $Encrypt(1\lambda,pp,\ m,(M,\rho))\rightarrow ct=((M,\rho),C,C\downarrow 0\ ,C\downarrow$

  $C=m\cdot(e(g,g)\uparrow\alpha\ )\uparrow s\ ,\{C\downarrow i,1=(w\uparrow\lambda\downarrow i\ \ v)\uparrow t\downarrow i\ ,C$ $3=$ $g\uparrow t\downarrow i\ \}\downarrow i\in[l]\ .$

  - Exponents $t\downarrow 1\ ,\ t\downarrow 2\ ,\ldots,t\downarrow l\in Z\downarrow p$ are chosen randomly.

**no attributes are fixed !**

**“secret sharing” layer**

**“attribute” layer Boneh-Boyen-style hash function**

**“bind” two layers**

# Our T-LU-CP-ABE System : Abstract

- $Decrypt(1\lambda, pp, sk\downarrow id, S, ct) \rightarrow m$.

  $C / e(K, C\downarrow 0 \uparrow K\uparrow\prime \ C\downarrow 0 \uparrow\prime) / \prod i \in I \uparrow \blacksquare (e(L \uparrow K\uparrow\prime \ L\uparrow\prime, C\downarrow i, 1) \ e(K\downarrow \tau, 1, C\downarrow i, 2) e(K\downarrow \tau, 2, C\downarrow i, 3)) \uparrow w\downarrow i = m$.

  - Constants $\{w\downarrow i\}$ satisfy $\sum i \in I \uparrow \blacksquare w\downarrow i \ M\downarrow i = (1, 0, \ldots, 0)$ .

- $Trace(pp, INS\downarrow(t, n), msk, sk) \rightarrow id \ or \ \perp$.

  - Test whether $sk$ is well-formed.
  - (1) extracts $(x\uparrow *, y\uparrow *)$ from $x||y = Dec\downarrow k\downarrow 2 \ (K\uparrow\prime)$ .

    (2) if $(x\uparrow *, y\uparrow *) \in \{(x\downarrow 1, y\downarrow 1), \ldots, (x\downarrow t-1, y\downarrow t-1)\}$ , compute $Dec\downarrow k\downarrow 1 \ (x\uparrow *)$ to get $id$.

    Otherwise, go to (3).

    (3) recover the secret $a\downarrow 0 \uparrow *$ of $INS\downarrow(t, n)$ by interpolating with $\{(x\downarrow 1, y\downarrow 1), \ldots, (x\downarrow t-1, y\downarrow t-1)\}$

    and $(x\uparrow * = x, y\uparrow * = y)$. If $a\downarrow 0 \uparrow * = f(0)$, compute $Dec\downarrow k\downarrow 1 \ (x\uparrow *)$ to get $id$.

    Otherwise, the algorithm outputs

**fully white-box traceability !**

# Conclusion

We constructed a **T-LU-CP-ABE** system, where

- Could trace the malicious users leaking the partial or modified decryption keys to others for profits.
- The attributes' size is unbounded and the public parameters' size does not grow linearly with the number of attributes.
- Optimize the system in tracing the malicious users to cut down the storage cost for traceability and to make the system efficient in the user revocation.

# Extensions

- Transform from One-Use T-LU-CP-ABE to Multi-Use T-LU-CP-ABE:
  - ✓ Extend our new T-LU-CP-ABE system to a multi-use system using the encoding technique in [LOSTW10].

- Revocable T-LU-CP-ABE :
  - ✓ Extend our new T-LU-CP-ABE system to a revocable system using ciphertext delegation and piecewise key generation introduced in [SSW12].

# Future Work

- To obtain a large universe CP-ABE system which supporting black-box traceability:
  - the malicious users leak their decryption devices instead of decryption keys.
  - the malicious users could hide the decryption algorithm by tweaking it, as well as the decryption keys.

- T-LU-CP-ABE System with public auditors:
  - to judge whether a user is in fact innocent or not.
  - the suspected user does not trust the system and the system needs to provide some evidence persuasive enough to prove that the suspected user is guilty.

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# Thanks.

## Q&A