Duality in ABE:

Converting Attribute Based Encryption for Dual Predicate and Dual Policy via Computational Encodings

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Our Main Results in One Slide

Generic dual conversion for ABE

Instantiations:

The first fully secure

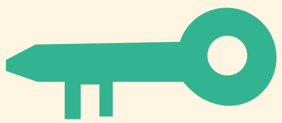
- CP-ABE with short key
- CP-ABE all-unbounded

(for boolean formulae, span programs)

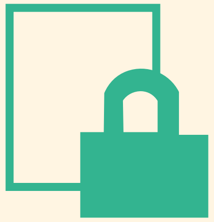
1 Introduction

Attribute Based Encryption (ABE)

ABE for predicate $R: X \times Y \rightarrow \{0,1\}$



Key for
$x \in X$



Ciphertext for
$y \in Y$
(encrypt m)

Decrypt

m if $R(x,y)=1$
? if $R(x,y)=0$

A Predicate

$R: X \times Y \to \{0,1\}$

Its Dual Predicate

$\bar{R}: Y \times X \to \{0,1\}$

$\bar{R}(y,x) := R(x,y)$

Key-Policy ABE

$R: P \times A \rightarrow \{0,1\}$

Key for policy p∈P

Ciphertext for attribute a∈A

R(p,a) iff p satisfies a

Ciphertext-Policy ABE

$\bar{R}: A \times P \rightarrow \{0,1\}$

Key for attribute a∈A

Ciphertext for policy p∈P

$\bar{R}$(a,p) iff p satisfies a

Motivation

- KP-ABE, CP-ABE
  - Definitions: directly related.
  - Constructions: NO known relation.
- **Can we generically convert an ABE to its dual?**
  - So that we would only construct KP, and get also CP.
  - Might be difficult? Historically, CP [BSW07, Waters11] was harder to achieve than KP [GPSW06].

Related Work for Dual Conversion

- Converting KP-ABE for boolean formulae predicate
  - Small classes of predicates
  - Its dual CP: only for bounded-size formulae [GJPS08].
- Converting KP-ABE for all boolean circuits
  - Implies general predicates, but must start with ABE for circuits.
  - Its dual CP: only for bounded-size circuits [GGHSW13].
    - Due to the use of universal circuits.
- Summary: **less expressivity**, and much **less efficient.** ☹

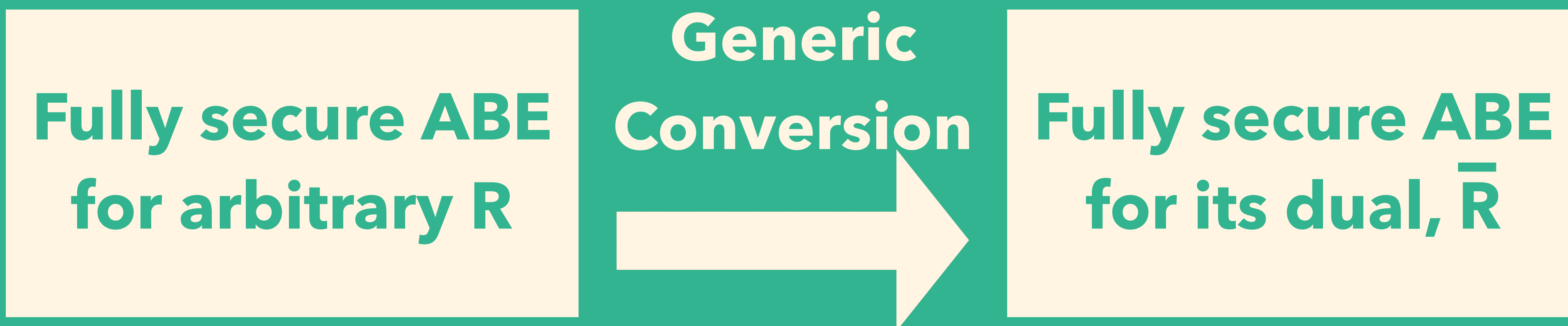
Our Focus

- Goal: Generic dual conversion for any predicate.
  - Preserving full security, expressivity, and efficiency.
- Tool: Use a generic ABE framework of [A14].
  - An abstraction of dual-system encryption [Waters09] for achieving fully-secure ABE.

[A14] N. Attrapadung, "Dual System Encryption via Doubly Selective Security: Framework, Fully-secure Functional Encryption for Regular Languages, and More", *Eurocrypt 2014*.

2 Our Result Overview

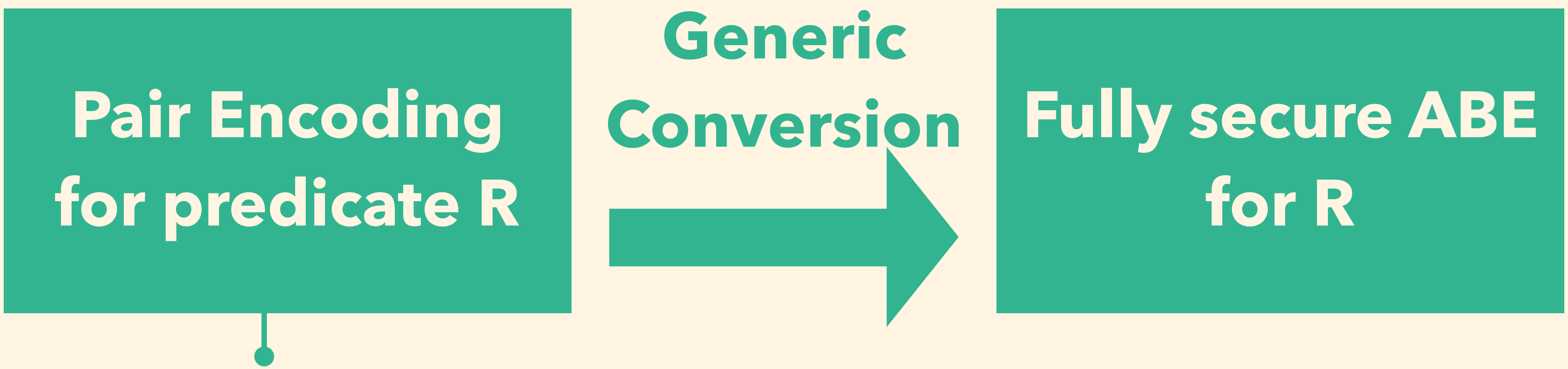
Our Main Result: Dual Conversion



Restricted to ABE In the “pair encoding” framework [A14].

Recall The “Pair Encoding” Framework

Main Theorem in [A14]



If pair encoding is

- **“Perfectly secure” or**
- **“Doubly selectively secure”.**

Our Main Result: More Precisely

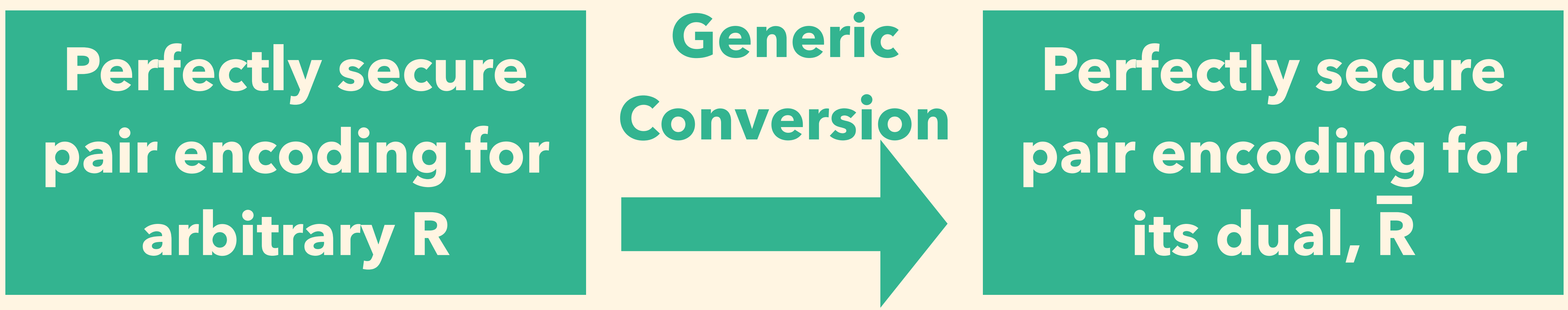
Doubly selective pair encoding for arbitrary R

Generic Conversion →

Doubly selective pair encoding for its dual, $\overline{R}$

The Only Previous Dual Conversion

A Side Result in [A14]



Implications: Solving Open Problems

No fully-secure ABE known before

[NEW! all implied by this work]

- CP unbounded boolean formula
- CP short-key for boolean formula
- CP over doubly-spatial

Doubly selective encodings known

- KP unbounded boolean formula
- KP short-ciphertext for boolean formula
- KP over doubly-spatial
- KP regular languages
- CP regular languages

[all in A14]

Perfectly secure encodings known

- KP, CP boolean formula with some bounds [LOSTW10, W14, A14]
- spatial, inner-product, …

3 Recall Pair Encoding

Recall Pair Encoding and ABE [A14]

Pair Encoding for R	$\longrightarrow$	ABE for R
Param $\longrightarrow$ $\boldsymbol{h}$		$PK=(g_1^{\boldsymbol{h}}, e(g_1,g_1)^{a})$, $MSK=a$
Enc1(x) $\longrightarrow$ $\boldsymbol{k}_x(a,\boldsymbol{r},\boldsymbol{h})$		$SK=g_1^{\boldsymbol{k}_x(a,\boldsymbol{r},\boldsymbol{h})}$
Enc2(y) $\longrightarrow$ $\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h})$		$CT=(g_1^{\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h})}, e(g_1,g_1)^{as_0}M)$
Pair($\boldsymbol{k}_x,\boldsymbol{c}_y$) $\longrightarrow$ as_0 if $R(x,y)=1$		$Dec \longrightarrow e(g_1,g_1)^{as_0}$ if $R(x,y)=1$

- s_0 = first entry in $\boldsymbol{s}$.
- Require some linearity properties.

- Use composite-order bilinear groups.
- (Neglect details here).

Security Definitions of Pair Encoding

Perfect security

Identical (info-theoretic) $\begin{cases} \boldsymbol{k}_x(0, \boldsymbol{r}, \boldsymbol{h}) \\ \boldsymbol{k}_x(a, \boldsymbol{r}, \boldsymbol{h}) \end{cases}$ $\quad \boldsymbol{c}_y(\boldsymbol{s}, \boldsymbol{h})$ for $R(x,y)=0$

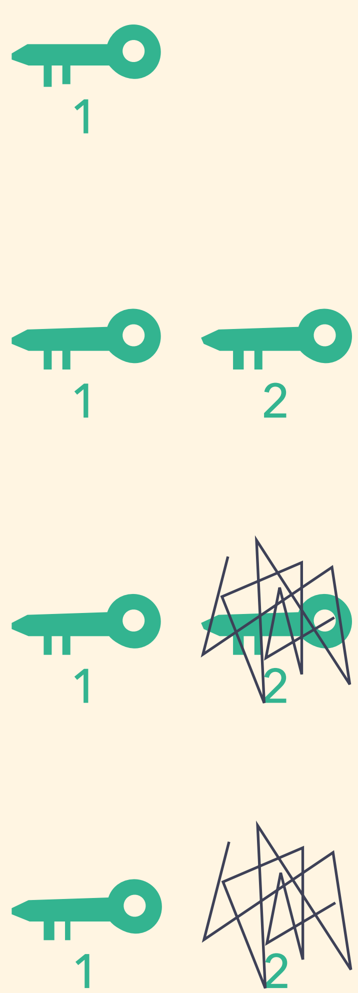
Doubly selective security

Cannot distinguish ⟵ $\begin{cases} g_2^{\boldsymbol{k}_x(0, \boldsymbol{r}, \boldsymbol{h})} \\ g_2^{\boldsymbol{k}_x(a, \boldsymbol{r}, \boldsymbol{h})} \end{cases}$ $\quad g_2^{\boldsymbol{c}_y(\boldsymbol{s}, \boldsymbol{h})}$ for $R(x,y)=0$

- **Selective notion:** queries ***c*** before ***k***. (then)
- **Co-selective notion:** queries ***k*** before ***c***. (then)

Intuition Behind Pair Encoding Security

Switch Keys from Normal to Semi-functional [A14]



normal: K — $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(0,\mathbf{0},\mathbf{0})}$

↓ Subgroup Decision

semi-1: K1 — $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(0,\hat{\mathbf{r}},\hat{\mathbf{h}})}$

↓ Security of encoding

semi-2: K2 — $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(\hat{a},\hat{\mathbf{r}},\hat{\mathbf{h}})}$

↓ Subgroup Decision

semi-3: K3 — $g_1^{\mathbf{k}(a,\mathbf{r},\mathbf{h})} \cdot g_2^{\mathbf{k}(\hat{a},\mathbf{0},\mathbf{0})}$

- Only for self-containment, will not use here.

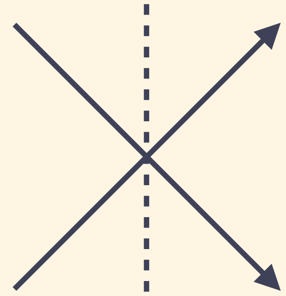
4 Our Conversion

Basic Idea for Dual Conversion

Encoding for R

Enc1 maps $x \in X$

Enc2 maps $y \in Y$



$\overline{\textbf{Encoding}}$ **for** $\overline{R}$

$\overline{\text{Enc1}}$ maps $y \in Y$ defined using Enc2

$\overline{\text{Enc2}}$ maps $x \in X$ defined using Enc1

Our Dual Conversion

Encoding for R

$\text{Param} \longrightarrow \boldsymbol{h}$

$\text{Enc1} \longrightarrow \boldsymbol{k}_x(a, \boldsymbol{r}, \boldsymbol{h})$

$\text{Enc2} \longrightarrow \boldsymbol{c}_y(\boldsymbol{s}, \boldsymbol{h})$

$\overline{\textbf{Encoding}}$ **for** $\bar{R}$

$\overline{\text{Param}} \longrightarrow \bar{\boldsymbol{h}} = (\boldsymbol{h}, \bar{b})$

$\overline{\text{Enc1}} \longrightarrow \bar{\boldsymbol{k}}_y(\bar{a}, \bar{\boldsymbol{s}}, \bar{\boldsymbol{h}}) = (\boldsymbol{c}_y(\boldsymbol{s}, \boldsymbol{h}),\ \bar{a} + \bar{b} s_0)$

$\overline{\text{Enc2}} \longrightarrow \bar{\boldsymbol{c}}_x(\bar{\boldsymbol{r}}, \bar{\boldsymbol{h}}) = (\boldsymbol{k}_x(\bar{b} \bar{s}_0, \boldsymbol{r}, \boldsymbol{h}),\ \bar{s}_0)$

where $\bar{\boldsymbol{s}} = \boldsymbol{s}$ $\quad \bar{\boldsymbol{r}} = (\bar{s}_0, \boldsymbol{r})$

Our Dual Conversion

Encoding for R

$\mathsf{Param} \rightarrow \boldsymbol{h}$

$\mathsf{Enc1} \rightarrow \boldsymbol{k}_x(a, \boldsymbol{r}, \boldsymbol{h})$

$\mathsf{Enc2} \rightarrow \boldsymbol{c}_y(\boldsymbol{s}, \boldsymbol{h})$

$\mathsf{Pair}(\boldsymbol{k}_x, \boldsymbol{c}_y) = as_0$

$\overline{\text{Encoding}}$ for $\overline{R}$

$\overline{\mathsf{Param}} \rightarrow \overline{\boldsymbol{h}} = (\boldsymbol{h}, \overline{b})$

$\overline{\mathsf{Enc1}} \rightarrow \overline{\boldsymbol{k}}_y(\overline{a}, \overline{\boldsymbol{s}}, \overline{\boldsymbol{h}}) = (\boldsymbol{c}_y(\boldsymbol{s}, \boldsymbol{h}),\ \overline{a} + \overline{b}s_0)$

$\overline{\mathsf{Enc2}} \rightarrow \overline{\boldsymbol{c}}_x(\overline{\boldsymbol{r}}, \overline{\boldsymbol{h}}) = (\boldsymbol{k}_x(\overline{b}\overline{s}_0, \boldsymbol{r}, \boldsymbol{h}),\ \overline{s}_0)$

$\overline{\mathsf{Pair}}$: $\mathsf{Pair}(\boldsymbol{k}_x, \boldsymbol{c}_y) = \overline{b}\overline{s}_0 s_0$

$(\overline{a} + \overline{b}s_0)(\overline{s}_0) - \overline{b}\overline{s}_0 s_0 = \overline{a}\overline{s}_0$

where $\overline{\boldsymbol{s}} = \boldsymbol{s}$ $\quad \overline{\boldsymbol{r}} = (\overline{s}_0, \boldsymbol{r})$

Our Dual Conversion

- The same conversion as in [A14].
- [A14] only proved for the **perfectly secure encodings.**
- We make it work also for **doubly secure encodings.**

Our New Theorems

Encoding for R is selective then → **$\overline{\text{Encoding}}$ for $\overline{R}$ is co-selective**

Encoding for R is co-selective then → **$\overline{\text{Encoding}}$ for $\overline{R}$ is selective**

Intuition:

- Swap key/cipher encodings $\rightarrow$ Query order is reversed.
- Hence selective becomes co-selective (and vice versa).

Difficulty in Proving Theorems

Encoding for R | $\overline{\textbf{Encoding for } R}$

Enc1: $\boldsymbol{k}_x(a,\boldsymbol{r},\boldsymbol{h})$

Enc2: $\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h})$

$\overline{\text{Enc1}}$: $\overline{\boldsymbol{k}}_y(\overline{a},\overline{\boldsymbol{s}},\overline{\boldsymbol{h}}) = (\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h}),\ \overline{a}+\overline{b}s_0)$

$\overline{\text{Enc2}}$: $\overline{\boldsymbol{c}}_x(\overline{\boldsymbol{r}},\overline{\boldsymbol{h}}) = (\boldsymbol{k}_x(\overline{b}\overline{s_0},\boldsymbol{r},\boldsymbol{h}),\ \overline{s_0})$

(all terms over the exponent)

Difficulty in Proving Theorems

Encoding for R

Enc1: $\left\{ \begin{array}{l} \boldsymbol{k}_x(0,\boldsymbol{r},\boldsymbol{h}) \\ \boldsymbol{k}_x(a,\boldsymbol{r},\boldsymbol{h}) \end{array} \right.$

Given IND here

Enc2: $\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h})$

$\overline{\textbf{Encoding}}$ **for** $\overline{R}$

$\overline{\text{Enc1}}$: $\overline{\boldsymbol{k}}_y(\overline{a},\overline{\boldsymbol{s}},\overline{\boldsymbol{h}}) = (\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h}),\ \overline{a}+\overline{b}s_0)$

$\overline{\text{Enc2}}$: $\overline{\boldsymbol{c}}_x(\overline{\boldsymbol{r}},\overline{\boldsymbol{h}}) = (\boldsymbol{k}_x(\overline{bs_0},\boldsymbol{r},\boldsymbol{h}),\ \overline{s_0})$

(all terms over the exponent)

Difficulty in Proving Theorems

Encoding for R

Enc1: $\left\{ \begin{array}{l} \boldsymbol{k}_x(0,\boldsymbol{r},\boldsymbol{h}) \\ \boldsymbol{k}_x(a,\boldsymbol{r},\boldsymbol{h}) \end{array} \right.$

Given IND here

Enc2: $\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h})$

$\overline{\text{Encoding}}$ for $\overline{R}$

$\overline{\text{Enc1}}$: $\left\{ \begin{array}{l} \overline{\boldsymbol{k}}_y(0,\overline{\boldsymbol{s}},\overline{\boldsymbol{h}}) \\ \overline{\boldsymbol{k}}_y(\overline{a},\overline{\boldsymbol{s}},\overline{\boldsymbol{h}}) = (\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h}),\ \overline{a}+\overline{b}s_0) \end{array} \right.$

Goal: to prove IND here.
But it totally differs from $\boldsymbol{k}_x$.

$\overline{\text{Enc2}}$: $\overline{\boldsymbol{c}}_x(\overline{\boldsymbol{r}},\overline{\boldsymbol{h}}) = (\boldsymbol{k}_x(\overline{b}\overline{s_0},\boldsymbol{r},\boldsymbol{h}),\ \overline{s_0})$

(all terms over the exponent)

Proof Idea

Encoding for R	$\overline{\textbf{Encoding for } R}$
Enc1: $\boldsymbol{k}_x(a,\boldsymbol{r},\boldsymbol{h})$	$\overline{\text{Enc1}}$: $\overline{\boldsymbol{k}}_y(\overline{a},\overline{\boldsymbol{s}},\overline{\boldsymbol{h}}) = (\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h}),\ \overline{a}+\overline{b}s_0)$
Enc2: $\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h})$	$\overline{\text{Enc2}}$: $\overline{\boldsymbol{c}}_x(\overline{\boldsymbol{r}},\overline{\boldsymbol{h}}) = (\boldsymbol{k}_x(\overline{b}\overline{s_0},\boldsymbol{r},\boldsymbol{h}),\ \overline{s_0})$

(all terms over the exponent)

Proof Idea

Encoding for R | **$\overline{\text{Encoding for}}$ $\overline{R}$**

Enc1: $\boldsymbol{k}_x(a,\boldsymbol{r},\boldsymbol{h})$

$\overline{\text{Enc1}}$: $\overline{\boldsymbol{k}}_y(\overline{a},\overline{\boldsymbol{s}},\overline{\boldsymbol{h}}) = (\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h}),\ \overline{a}+\overline{b}s_0)$

Enc2: $\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h})$

$\overline{\text{Enc2}}$: $\overline{\boldsymbol{c}}_x(\overline{\boldsymbol{r}},\overline{\boldsymbol{h}}) = (\boldsymbol{k}_x(\overline{b}\overline{s_0},\boldsymbol{r},\boldsymbol{h}),\ \overline{s_0})$

Sim

attacks Enc

Adv

attacks $\overline{\text{Enc}}$

(all terms over the exponent)

Proof Idea

Encoding for R

$\overline{\text{Encoding}}$ for $\overline{R}$

define $\bar{a}$ on unknown a

Enc1: $\boldsymbol{k}_x(a, \boldsymbol{r}, \boldsymbol{h})$

$\overline{\text{Enc1}}$: $\bar{\boldsymbol{k}}_y(\bar{a}, \bar{\boldsymbol{s}}, \bar{\boldsymbol{h}}) = (\boldsymbol{c}_y(\boldsymbol{s}, \boldsymbol{h}),\ \bar{a} + \bar{b} s_0)$

Enc2: $\boldsymbol{c}_y(\boldsymbol{s}, \boldsymbol{h})$

$\overline{\text{Enc2}}$: $\bar{\boldsymbol{c}}_x(\bar{\boldsymbol{r}}, \bar{\boldsymbol{h}}) = (\boldsymbol{k}_x(\bar{b}\bar{s}_0, \boldsymbol{r}, \boldsymbol{h}),\ \bar{s}_0)$

Sim

attacks Enc

Adv

attacks $\overline{\text{Enc}}$

(all terms over the exponent)

Proof Idea

Encoding for R

$\overline{\text{Encoding}}$ for $\overline{R}$

define $\overline{a}$ on unknown a

Enc1: $\boldsymbol{k}_x(a,\boldsymbol{r},\boldsymbol{h})$

$\overline{\text{Enc1}}$: $\overline{\boldsymbol{k}}_y(\overline{a},\overline{\boldsymbol{s}},\overline{\boldsymbol{h}}) = (\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h}),\ \overline{a}+\overline{b}s_0)$

But this becomes unknown, too.

Enc2: $\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h})$

$\overline{\text{Enc2}}$: $\overline{\boldsymbol{c}}_x(\overline{\boldsymbol{r}},\overline{\boldsymbol{h}}) = (\boldsymbol{k}_x(\overline{b}\overline{s_0},\boldsymbol{r},\boldsymbol{h}),\ \overline{s_0})$

Sim

attacks Enc

Adv

attacks $\overline{\text{Enc}}$

(all terms over the exponent)

Proof Idea: Cancellation Trick

Encoding for R

$\overline{\textbf{Encoding}}$ **for** $\overline{R}$

define $\bar{a}$ on unknown a

Enc1: $\mathbf{k}_x(a,\mathbf{r},\mathbf{h})$

$\overline{\text{Enc1}}$: $\overline{\mathbf{k}}_y(\bar{a},\bar{\mathbf{s}},\bar{\mathbf{h}}) = (\mathbf{c}_y(\mathbf{s},\mathbf{h}),\ \bar{a}+\bar{b}s_0)$

Enc2: $\mathbf{c}_y(\mathbf{s},\mathbf{h})$

$\overline{\text{Enc2}}$: $\overline{\mathbf{c}}_x(\bar{\mathbf{r}},\bar{\mathbf{h}}) = (\mathbf{k}_x(\bar{b}\bar{s}_0,\mathbf{r},\mathbf{h}),\ \bar{s}_0\ )$

Sim

attacks Enc

Adv

attacks $\overline{\text{Enc}}$

(all terms over the exponent)

Proof Idea: Cancellation Trick

Encoding for R	$\overline{\textbf{Encoding for}\ R}$

define $\bar{a}$ on unknown a

Enc1: $\boldsymbol{k}_x(a,\boldsymbol{r},\boldsymbol{h})$ $\quad$ $\overline{\text{Enc1}}$: $\bar{\boldsymbol{k}}_y(\bar{a},\bar{\boldsymbol{s}},\bar{\boldsymbol{h}}) = (\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h}),\ \bar{a}+\bar{b}s_0)$

define $\bar{b}$ on unknown a

Enc2: $\boldsymbol{c}_y(\boldsymbol{s},\boldsymbol{h})$ $\quad$ $\overline{\text{Enc2}}$: $\bar{\boldsymbol{c}}_x(\bar{\boldsymbol{r}},\bar{\boldsymbol{h}}) = (\boldsymbol{k}_x(\bar{b}s_0,\boldsymbol{r},\boldsymbol{h}),\ s_0)$

Sim

attacks Enc

Adv

attacks $\overline{\text{Enc}}$

(all terms over the exponent)

Proof Idea: Cancellation Trick

Encoding for R | $\overline{\textbf{Encoding for } R}$

define $\bar{a}$ on unknown a

cancellation of two unknowns!

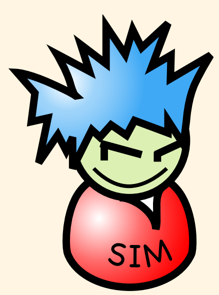
Enc1: $\mathbf{k}_x(a,\mathbf{r},\mathbf{h})$

$\overline{\text{Enc1}}$: $\bar{\mathbf{k}}_y(\bar{a},\bar{\mathbf{s}},\bar{\mathbf{h}}) = (\mathbf{c}_y(\mathbf{s},\mathbf{h}),\ \bar{a}+\bar{b}s_0)$

define $\bar{b}$ on unknown a

Enc2: $\mathbf{c}_y(\mathbf{s},\mathbf{h})$

$\overline{\text{Enc2}}$: $\bar{\mathbf{c}}_x(\bar{\mathbf{r}},\bar{\mathbf{h}}) = (\mathbf{k}_x(\bar{b}s_0,\mathbf{r},\mathbf{h}),\ \bar{s}_0)$



Sim

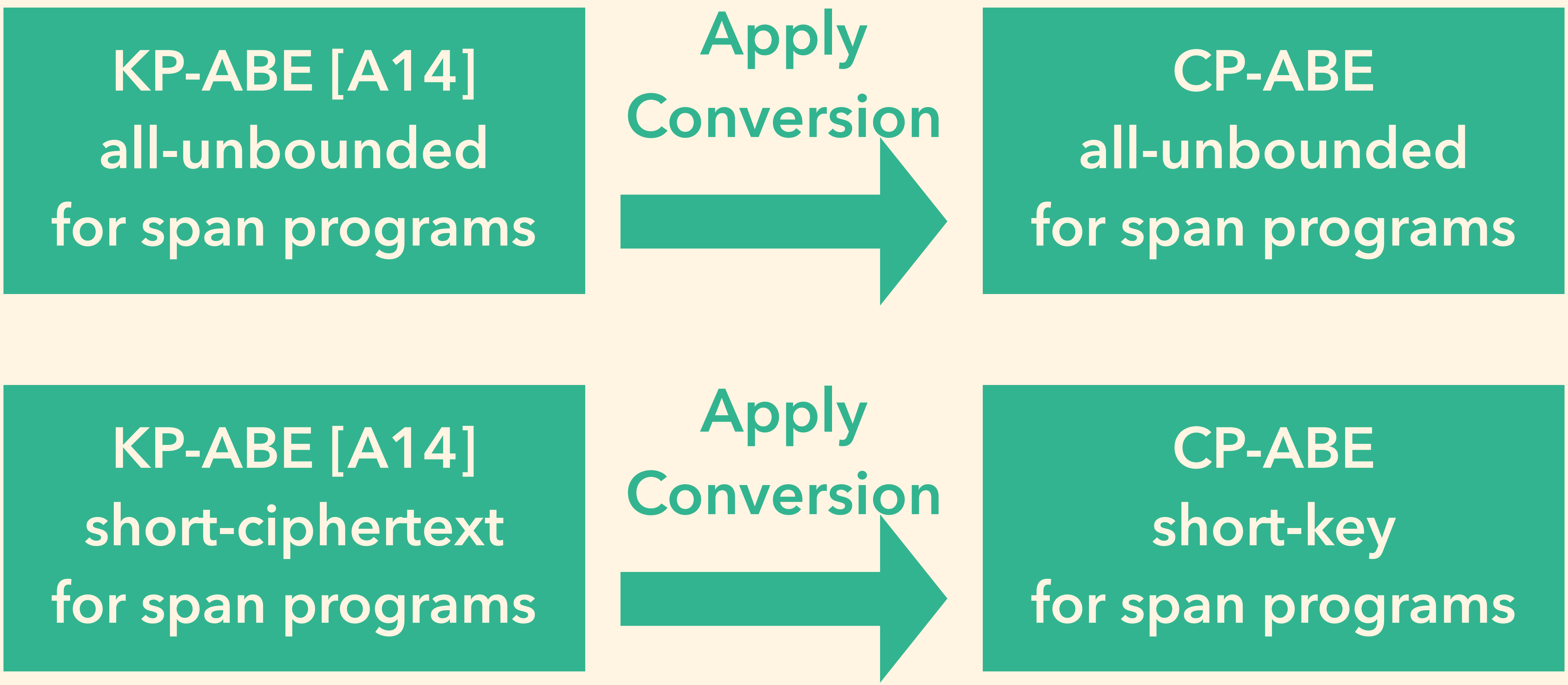
attacks Enc

Adv

attacks $\overline{\text{Enc}}$

(all terms over the exponent)

New Instantiations



Doubly selective secure under
some Extended DH Exponent assumptions [A14].

5 Concluding Remarks

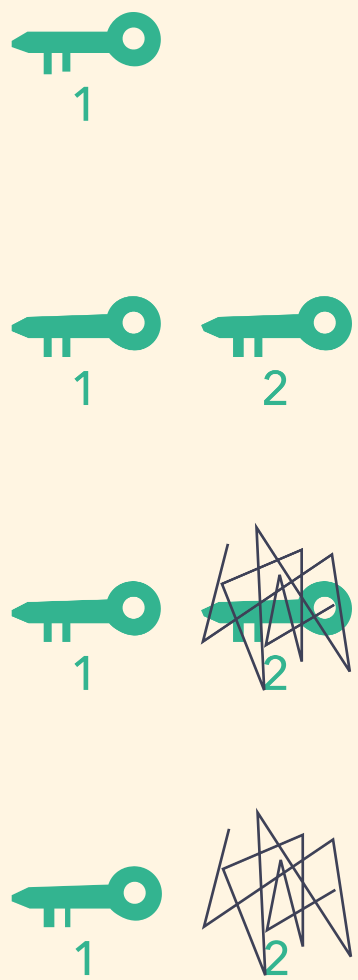
More Results

- Dual-Policy ABE
  - Conjunctively combine ABE and its dual [AI09].
  - We also provide a conversion from ABE to DP-ABE.
- More refinement:
  - New specific CP-ABE with tighter reduction.
- Full version at http://eprint.iacr.org/2015/157.

Thank you

Intuition Behind Pair Encoding Security

Switch Keys from Normal to Semi-functional [A14]



normal
K
$g_1^{\boldsymbol{k}(a,\boldsymbol{r},\boldsymbol{h})} \cdot g_2^{\boldsymbol{k}(0,\boldsymbol{0},\boldsymbol{0})}$

Subgroup Decision

semi-1
K1
$g_1^{\boldsymbol{k}(a,\boldsymbol{r},\boldsymbol{h})} \cdot g_2^{\boldsymbol{k}(0,\hat{\boldsymbol{r}},\hat{\boldsymbol{h}})}$

Security of encoding

semi-2
K2
$g_1^{\boldsymbol{k}(a,\boldsymbol{r},\boldsymbol{h})} \cdot g_2^{\boldsymbol{k}(\hat{a},\hat{\boldsymbol{r}},\hat{\boldsymbol{h}})}$

Subgroup Decision

semi-3
K3
$g_1^{\boldsymbol{k}(a,\boldsymbol{r},\boldsymbol{h})} \cdot g_2^{\boldsymbol{k}(\hat{a},\boldsymbol{0},\boldsymbol{0})}$

- Only for self-containment, will not use here.

RSAConference2015

San Francisco | April 20-24 | Moscone Center

Revocable Hierarchical Identity-Based Encryption: History-Free Update, Security Against Insiders, and Short Ciphertexts

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2. NICT, Japan

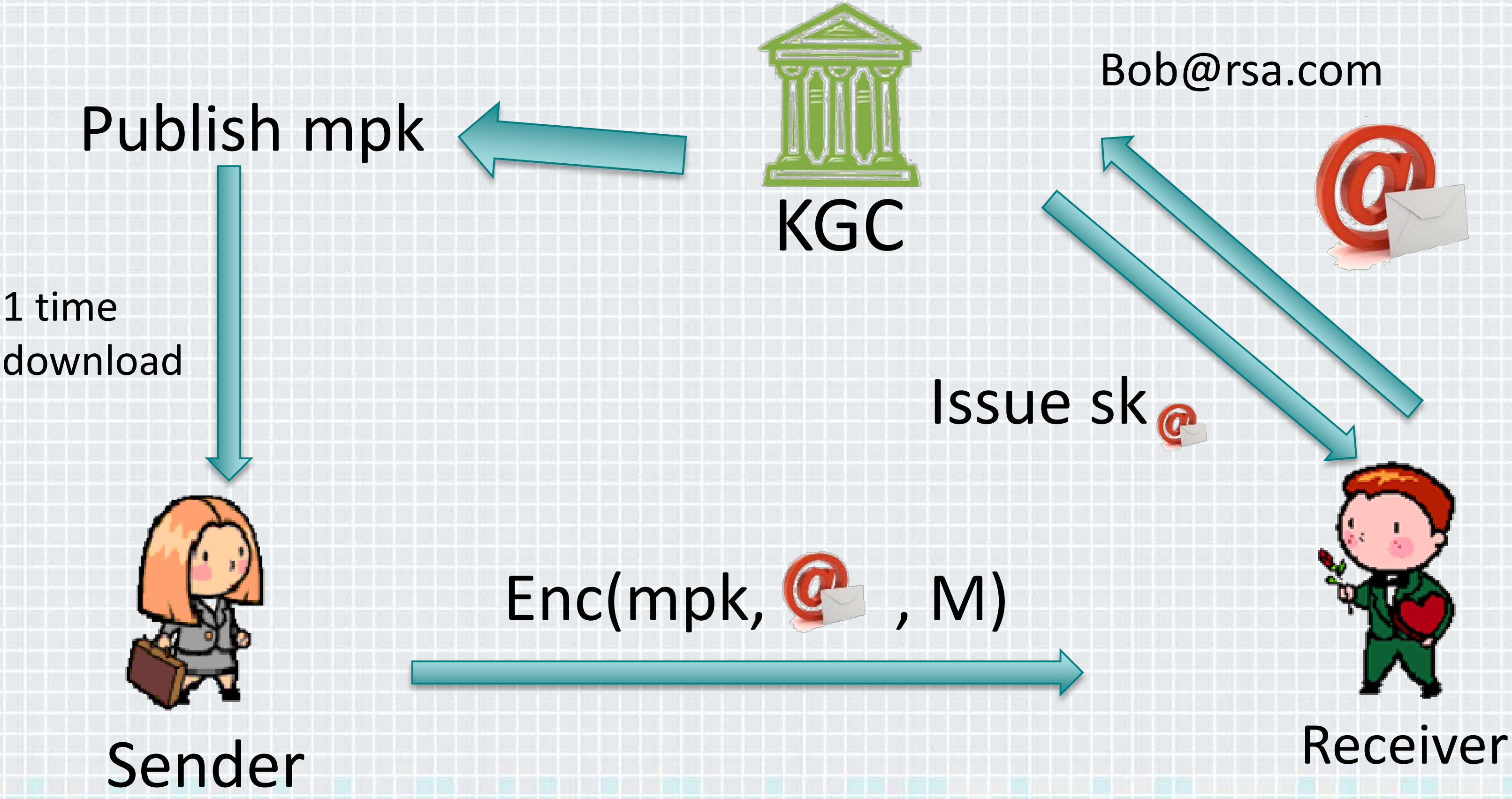
#RSAC

Contents

- Identity-based encryption with revocation (RIBE)
  - Trivial Way (by Boneh and Franklin 2001)
  - Scalable construction (by Boldyreva, Goyal, and Kumar, 2008)
- Revocable Hierarchical IBE (RHIBE): CT-RSA 2013, Seo and Emura
  - History-preserving updates approach
  - Security against outsider
  - Long-size ciphertext (ciphertext size depends on the level of hierarchy)
- Our RHIBE Constructions
  - History-free updates approach
  - Security against insider
  - Constant-size ciphertext (in terms of the hierarchy level)

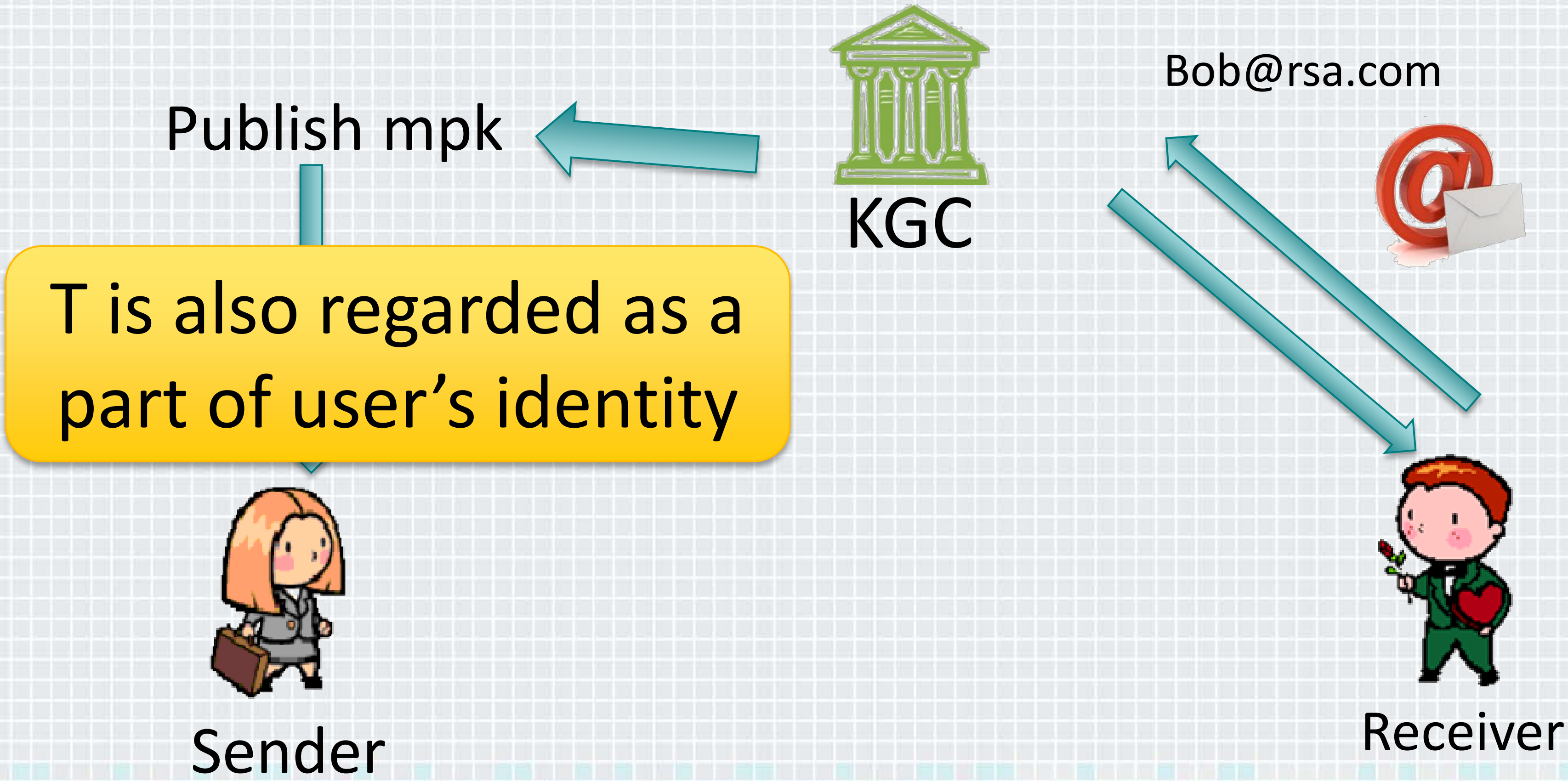
Identity-Based Encryption and Revocation

Identity-Based Encryption (IBE)



Identity-Based Encryption (IBE)

Revocation Capability in IBE: Boneh-Franklin



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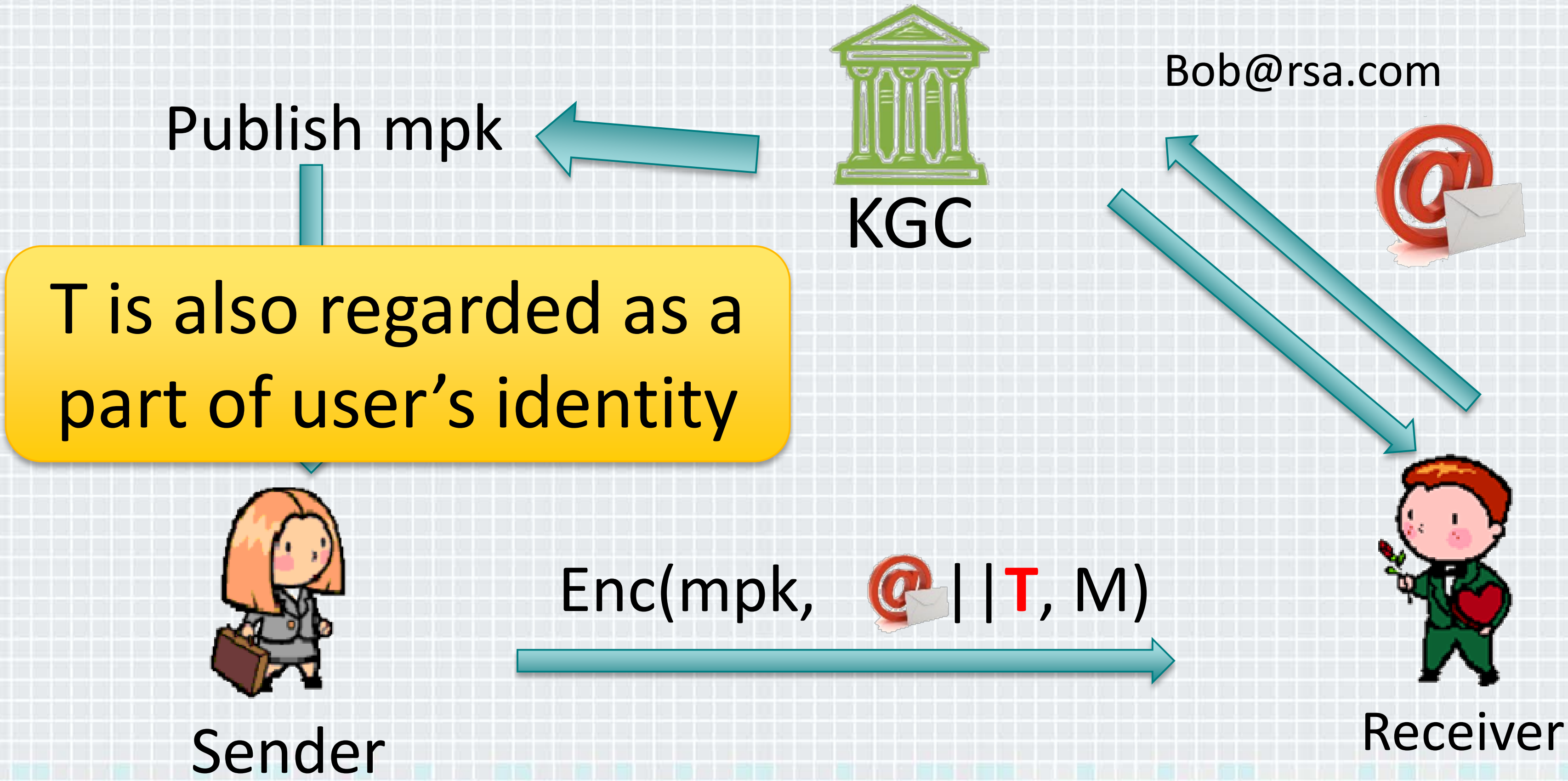

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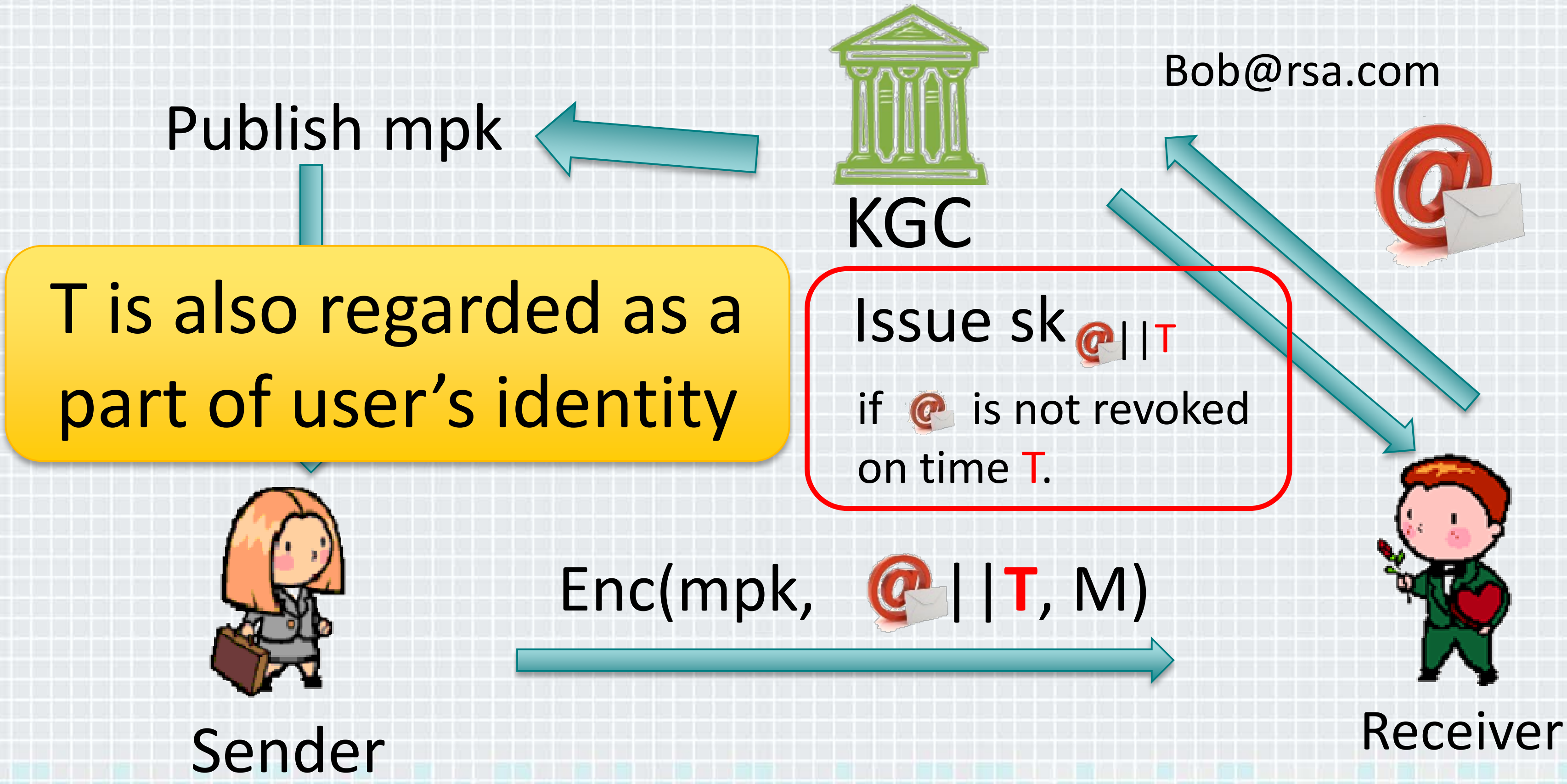
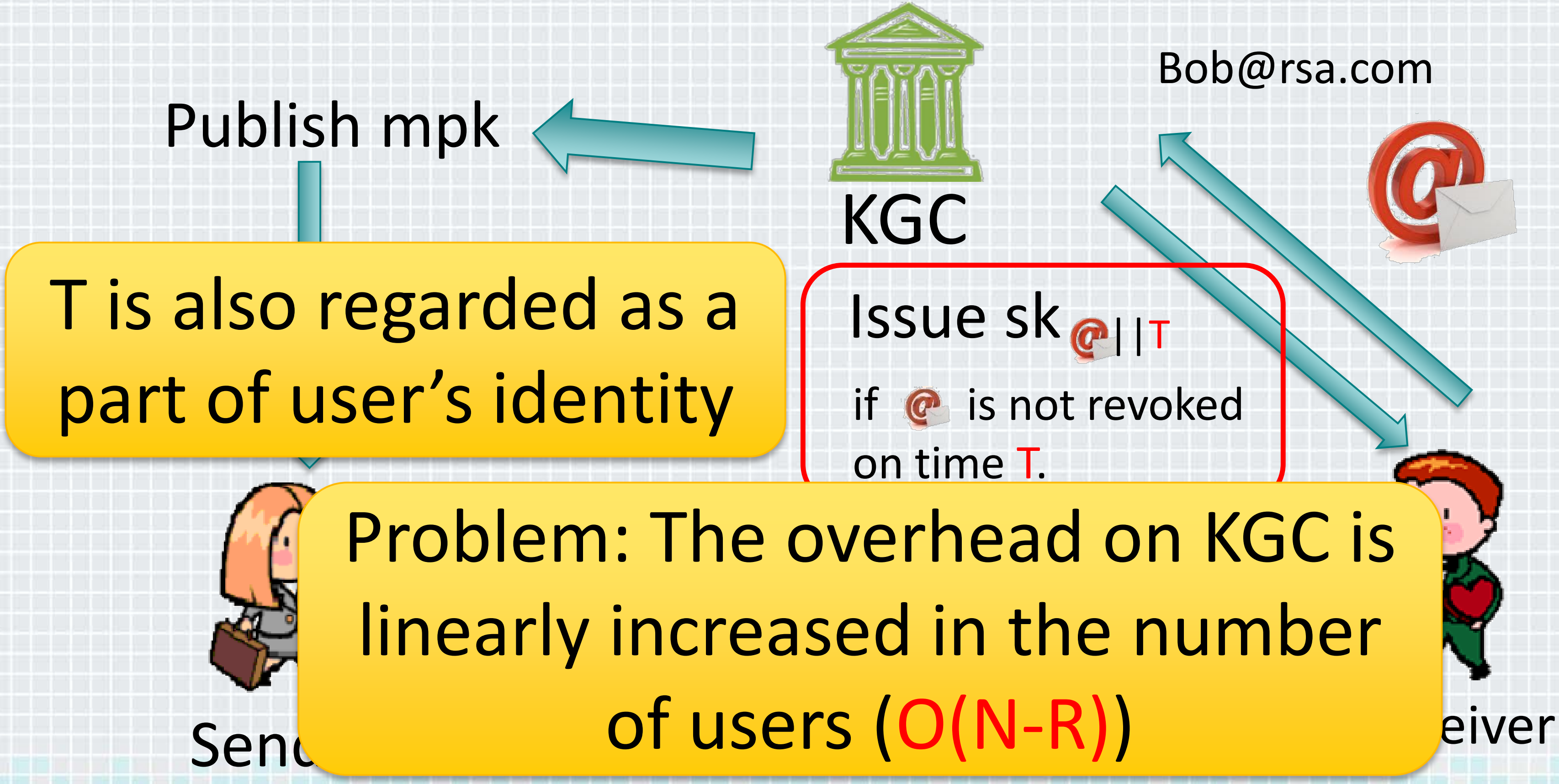


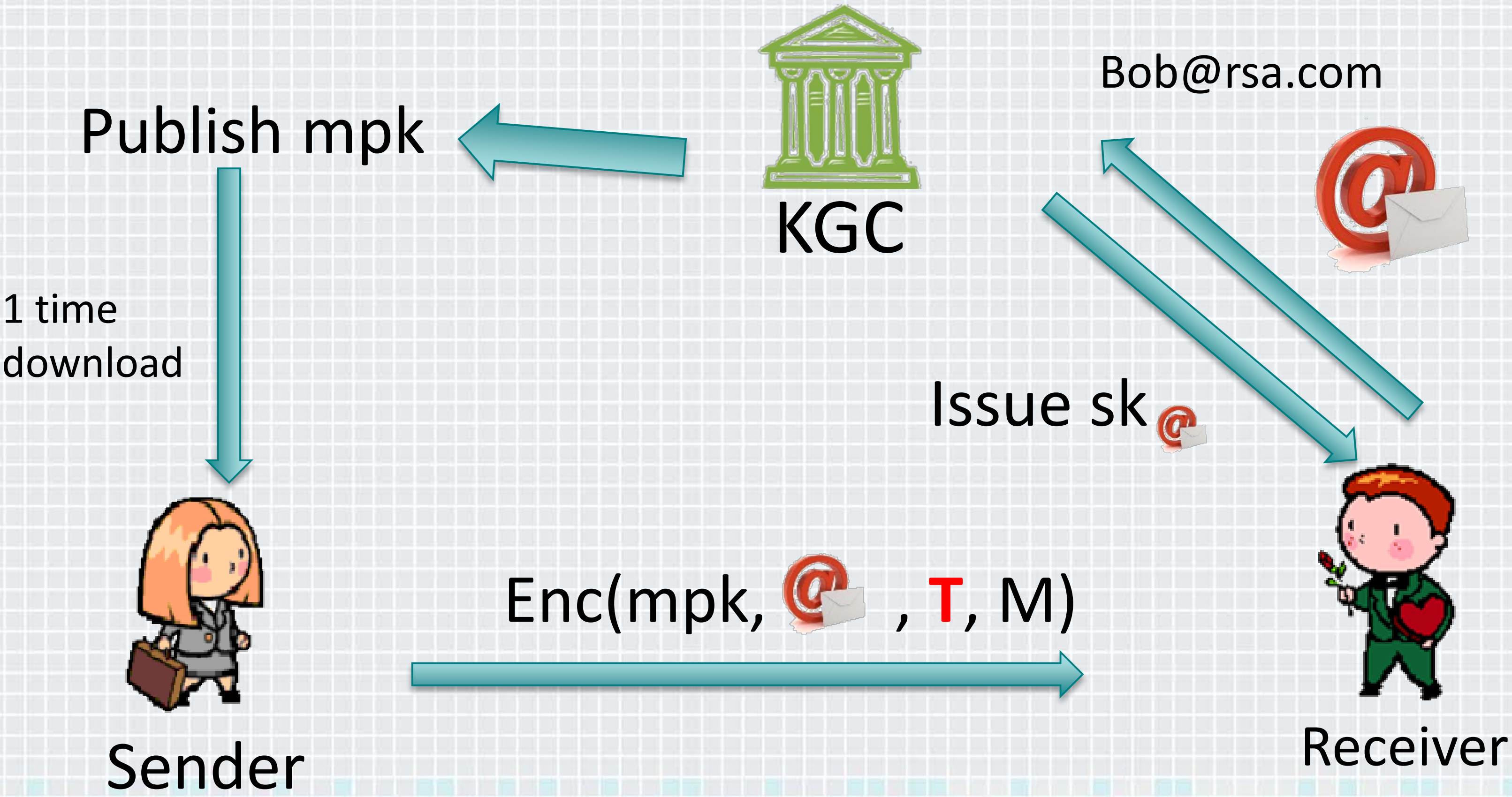
Revocation Capability in IBE: Boneh-Franklin



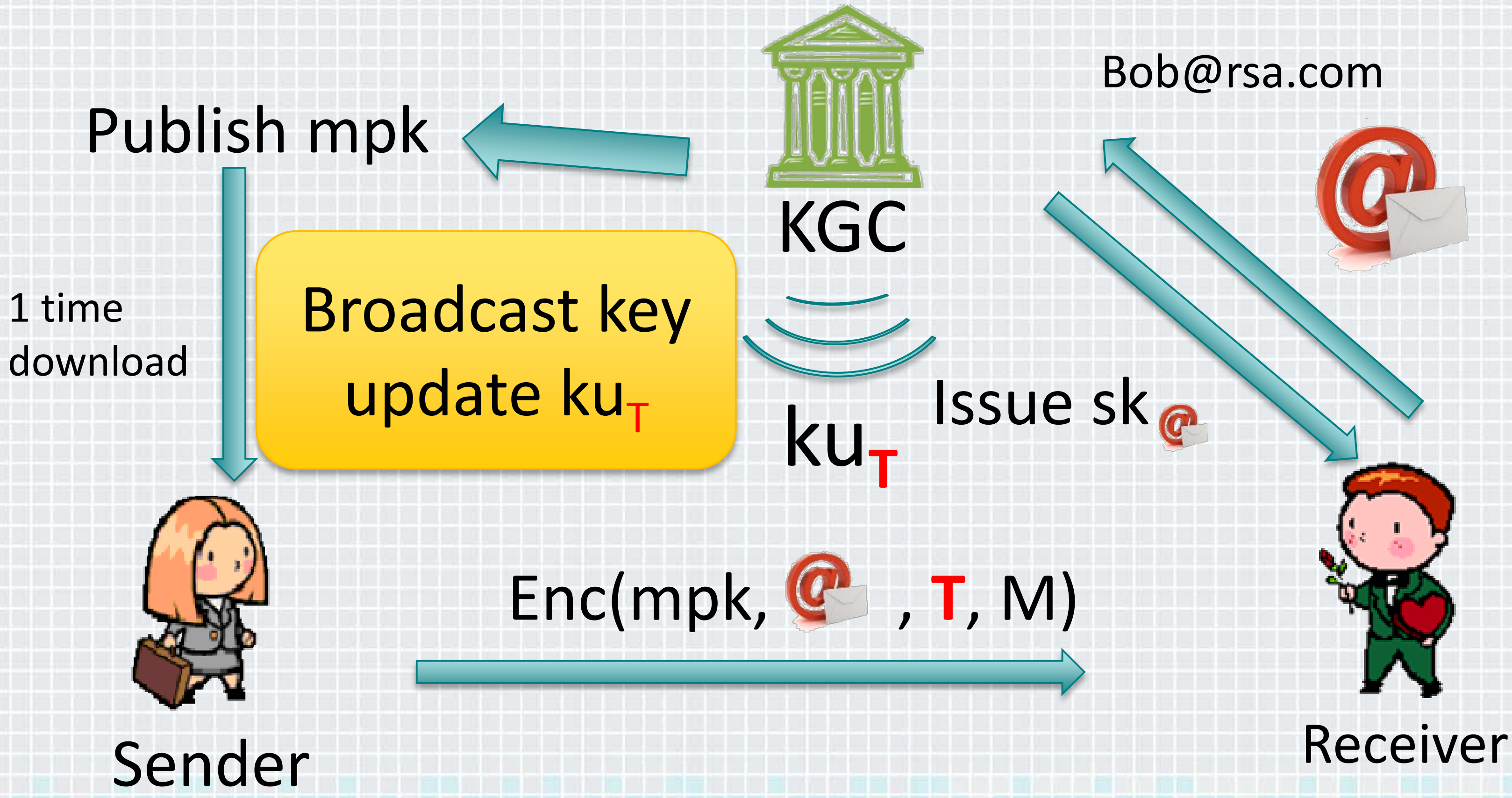
T is also regarded as a part of user's identity

Problem: The overhead on KGC is linearly increased in the number of users (O(N-R))

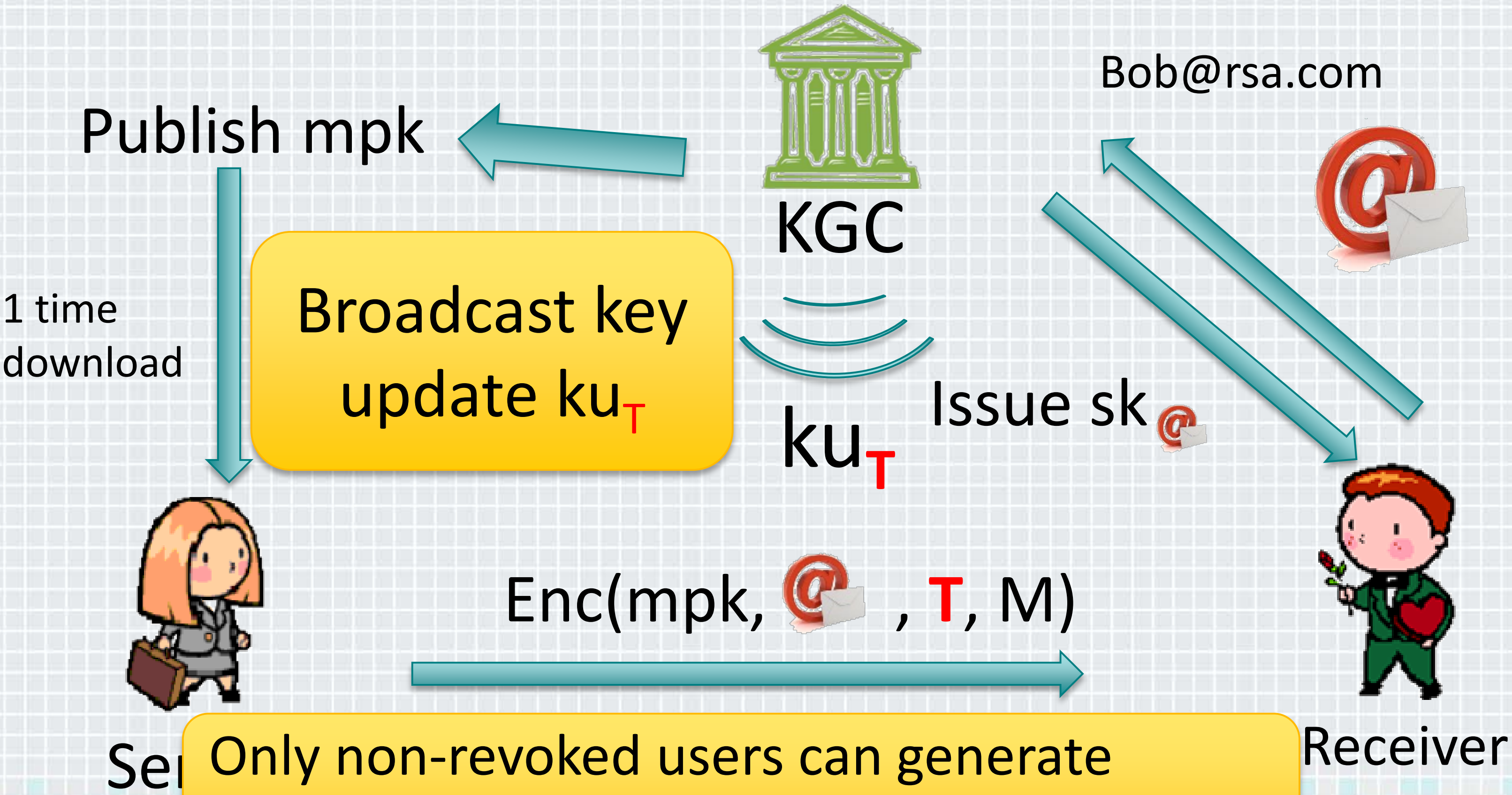
Revocation Capability in IBE: Boldyreva et al.



Revocation Capability in IBE: Boldyreva et al.

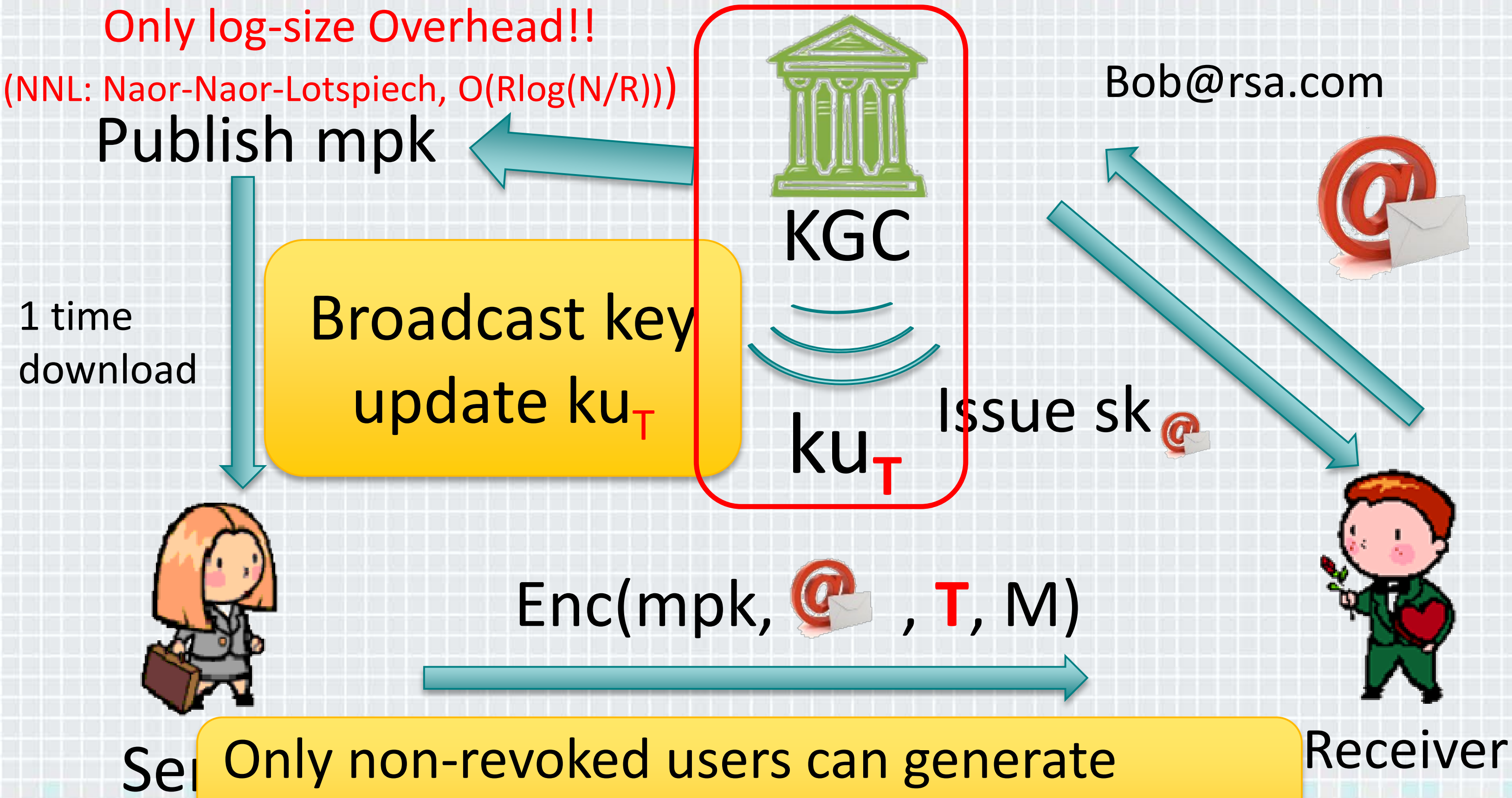


Revocation Capability in IBE: Boldyreva et al.



Only non-revoked users can generate a decryption key dk ,T from ku_T and sk

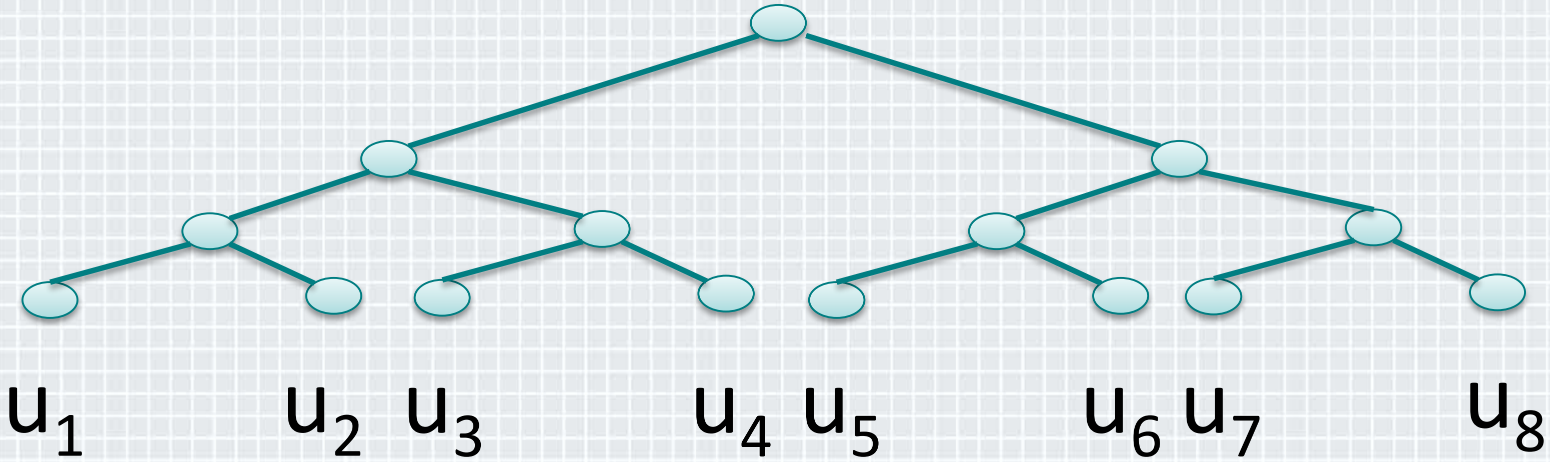
Revocation Capability in IBE: Boldyreva et al.



Only non-revoked users can generate a decryption key dk ,T from ku_T and sk

Broadcast Encryption (BE) Technique
Complete Subtree (CS)

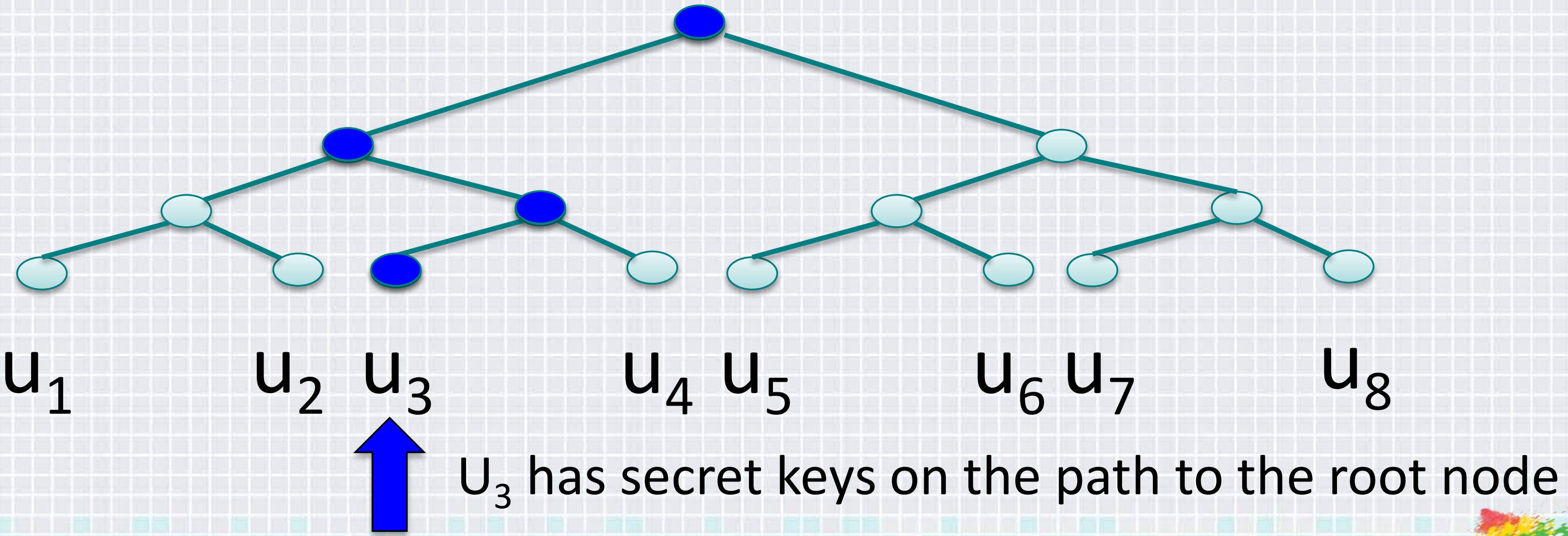
- Each user is assigned to a node



We consider a binary tree kept by KGC

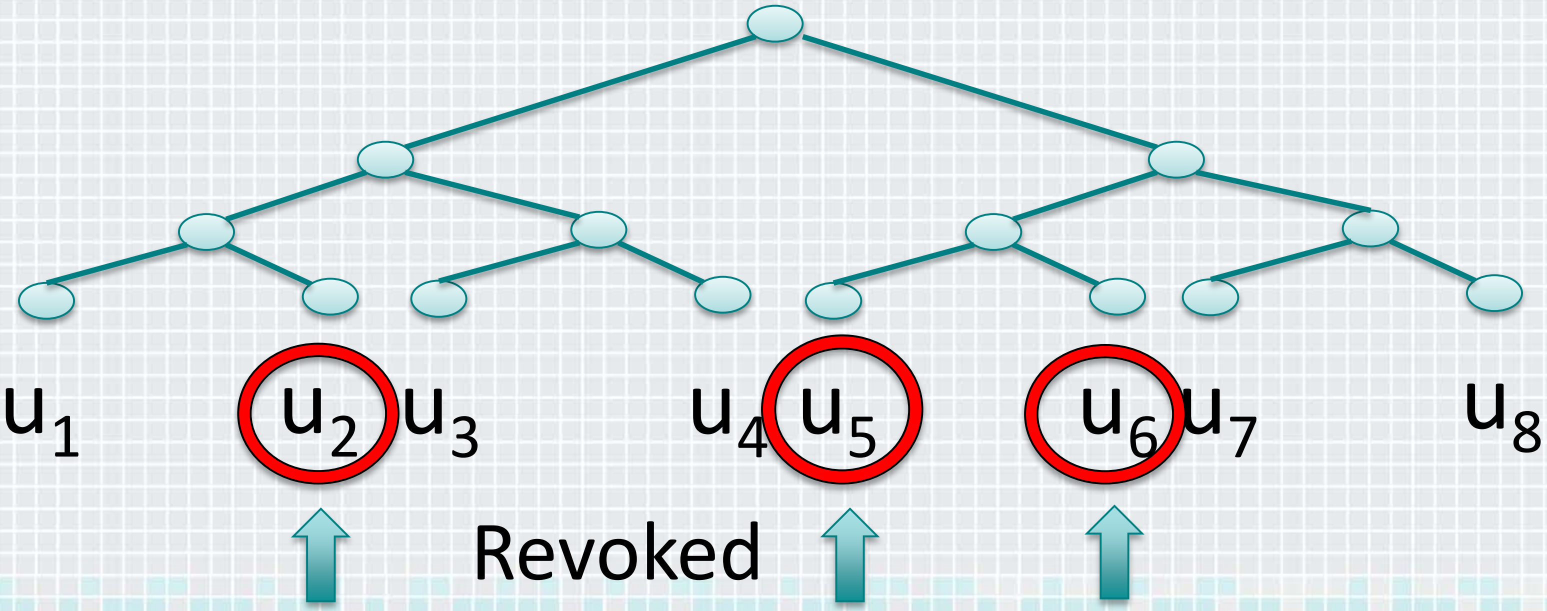
Broadcast Encryption (BE) Technique Complete Subtree (CS)

- Each user is issued secret keys on the path to the root node by KGC (sk)



Broadcast Encryption (BE) Technique
Complete Subtree (CS)

- ku_T is computed for nodes which do not have intersection against paths (to the root node) of revoked users



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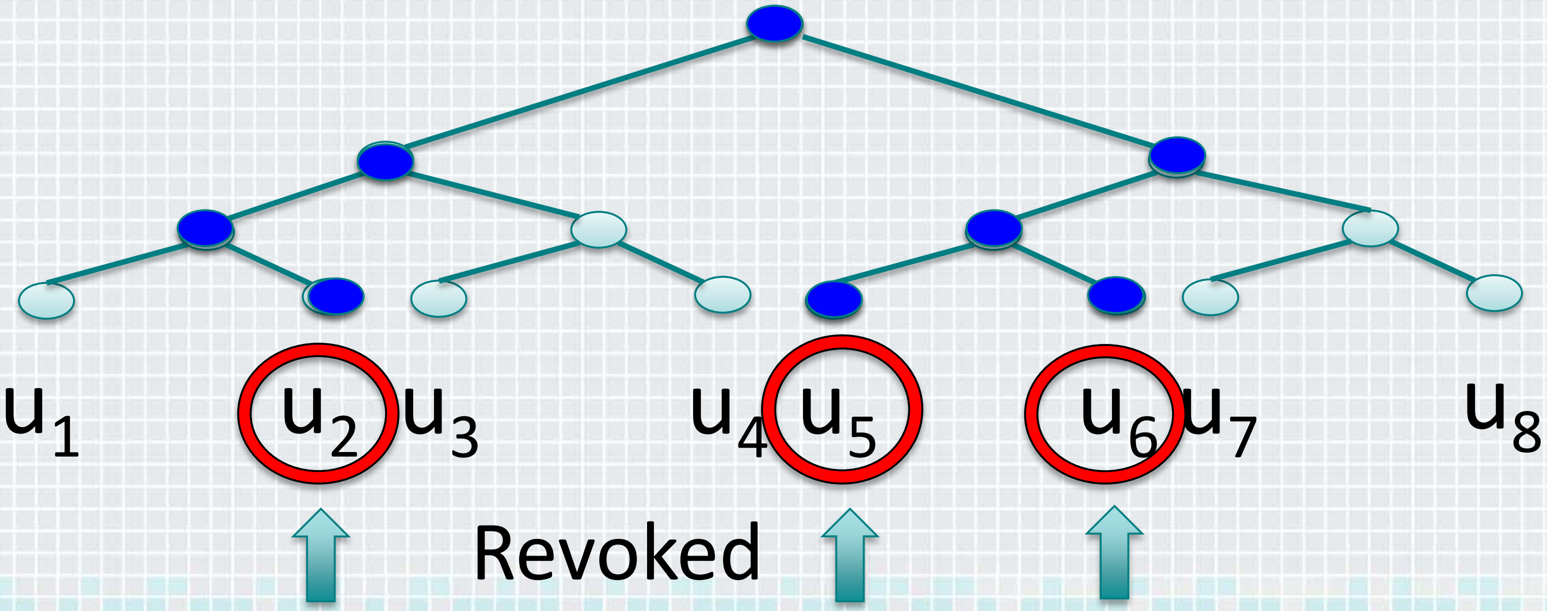

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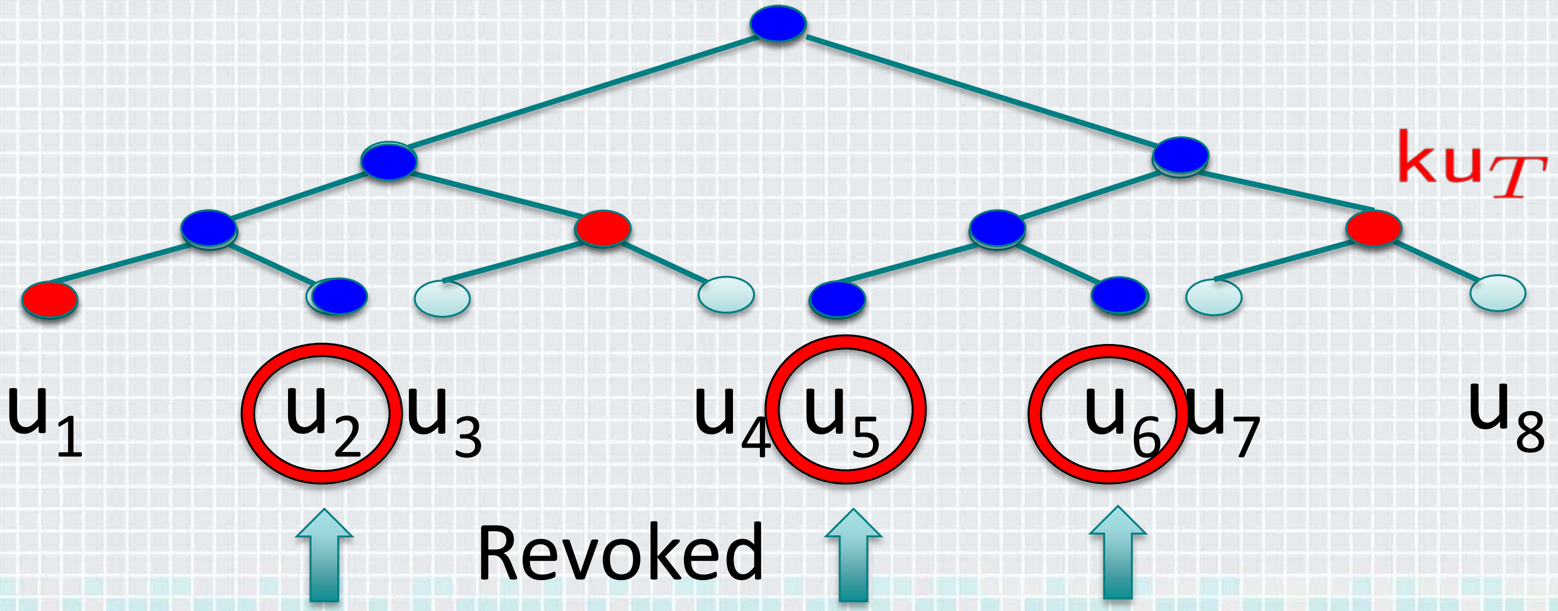

Broadcast Encryption (BE) Technique
Complete Subtree (CS)

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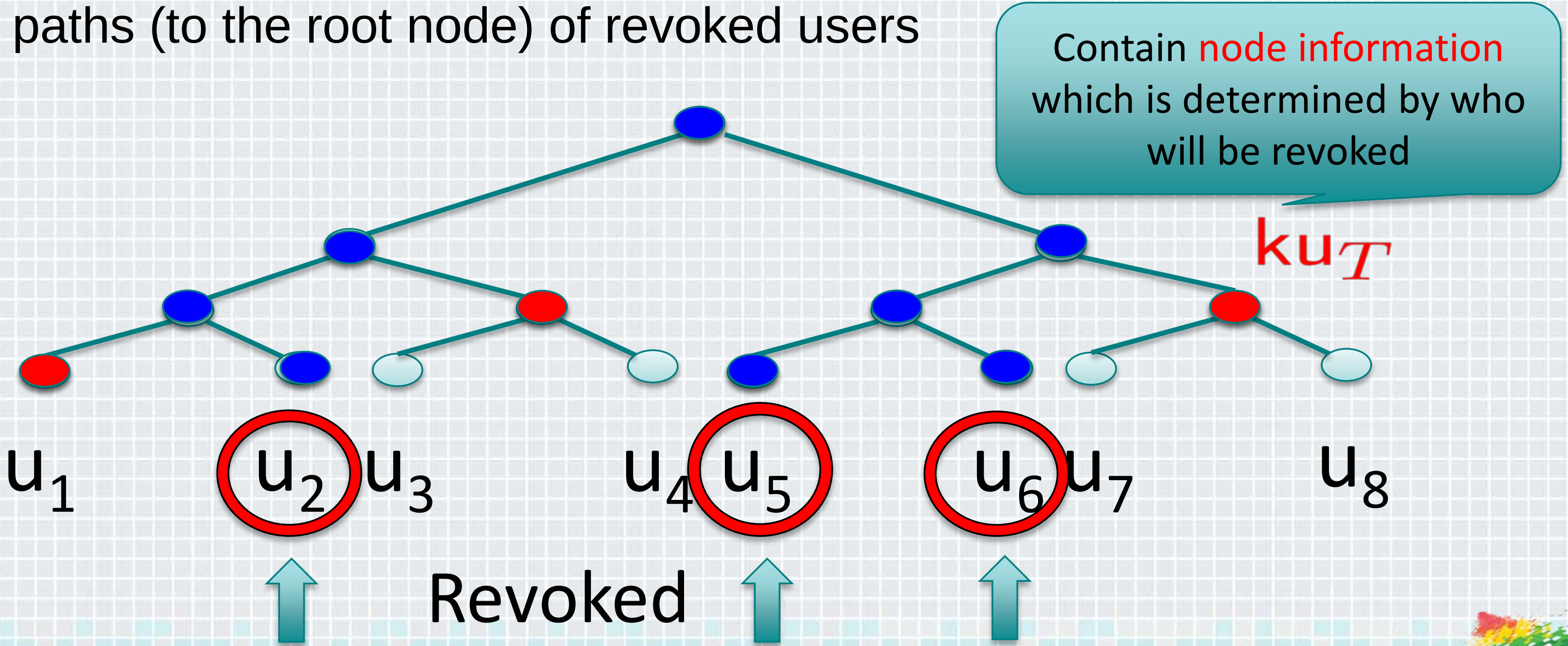
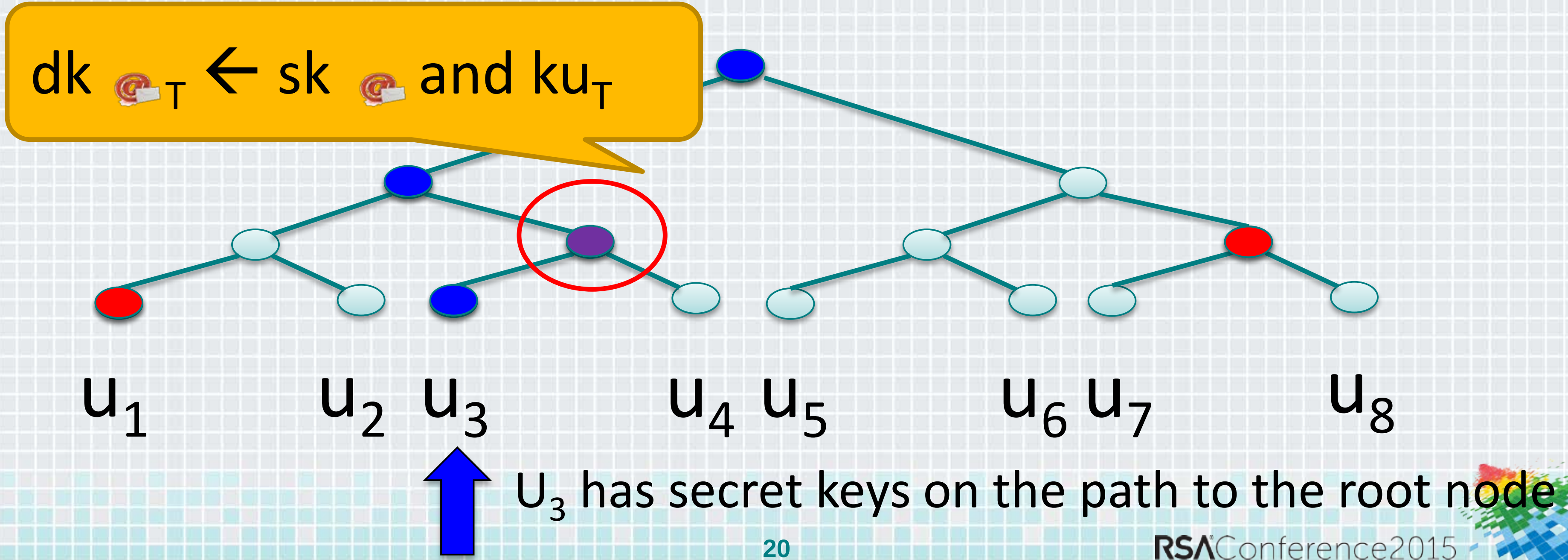


Broadcast Encryption (BE) Technique
Complete Subtree (CS)

- From log N size public information ku_T, only non-revoked users can extract useful information.



Scalable Revocable IBE

- First construction
  - A. Boldyreva, V. Goyal, and V. Kumar. Identity-based encryption with efficient revocation. In ACM CCS 2008
- First adaptive secure scheme
  - B. Libert and D. Vergnaud. Adaptive-ID secure revocable identity-based encryption. In CT-RSA 2009.
- Considering decryption key exposure resistance
  - J. H. Seo and K. Emura. Revocable identity-based encryption revisited: Security model and construction. In PKC 2013.
  - An adversary is allowed to obtain

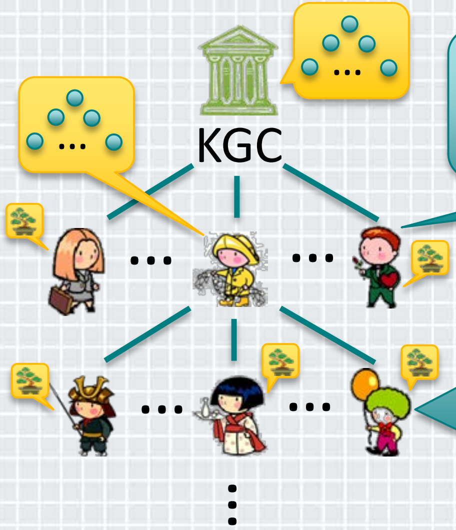
$$dk_{ID,T} \text{ if } (ID, T) \neq (ID^*, T^*)$$

- SD-based construction
  - K. Lee, D. H. Lee, and J. H. Park. Efficient revocable identity-based encryption via subset difference methods, eprint.iacr.org/2014/132, 2014.

Revocable Hierarchical IBE (RHIBE)

Revocable Hierarchical IBE (RHIBE)

- A low-level user can stay in the system only if her parent also stays in the current time period.



First-level users have O(log N)-size secret key (as in RIBE)

Second-level users have log N subkeys for "each" parent's subkey (in total $(\log N)^2$-size subkeys)

$skID_1 = \{ subkey_1, \ldots, subkey_{logN} \}$

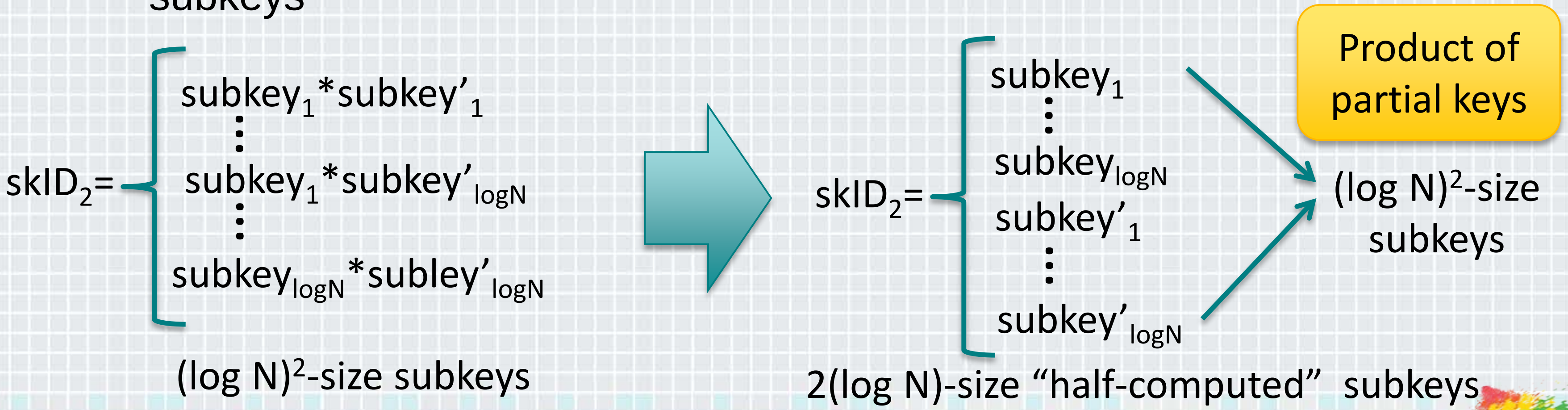
One of subkeys will be used for computing kuT.

$skID_2 = \{ subkey_1 * subkey'_1, \ldots, subkey_1 * subkey'_{logN}, \ldots, subkey_{logN} * subley'_{logN} \}$

- Trivial combination of RIBE and HIBE will result in an impractical scheme with an exponential number of secret keys

Revocable Hierarchical IBE (RHIBE)

- The first RHIBE scheme with polynomial size secret keys (Seo-Emura, CT-RSA 2013)
  - Asymmetric trade between secret key size and generating time for secret key
    - A parent gives “half-computed” subkeys, and children generate suitable subkeys



Revocable Hierarchical IBE (RHIBE)

- The first RHIBE scheme with polynomial size secret keys (Seo-Emura, CT-RSA 2013)

size and generating time for

, and children generate suitable

History-preserving key updates

- For the calculation, a child needs to know which partial key of the ancestor was used in each time period.
- Such information is also announced in the key updates

$$ku_{ID_{|\ell-1},T} := \{\{Lv_i\}_{i \in [1,\ell-1]}, \vec{f}_{ID_{|\ell-1},\theta}\}$$

$(\log N)^2$-size subkeys

=
subkey$_1$
⋮
subkey$_{\log N}$
subkey'$_1$
⋮
subkey'$_{\log N}$

$(\log N)^2$-size subkeys

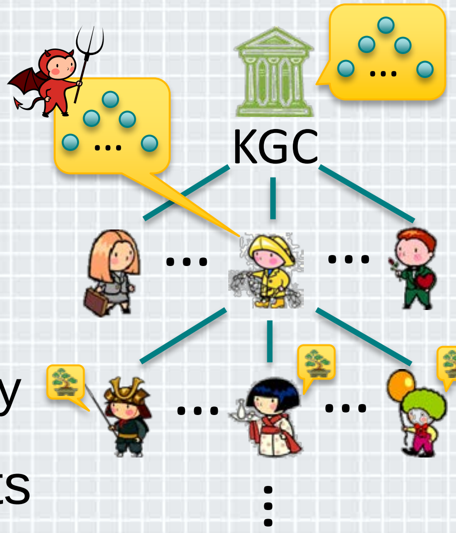
Product of partial keys

2(log N)-size “half-computed” subkeys

#RSAC

Our Contribution

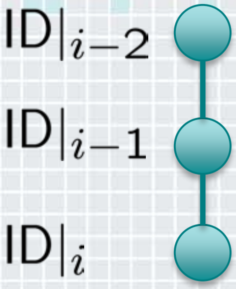
- History-Free Update
  - Low-level users do not need to know what ancestors did during key updates.
- Security Against Insiders
  - An adversary is allowed to obtain state information
- Short Ciphertexts
  - Constant-size ciphertext in terms of the level of hierarchy
- Two constructions: Shorter secret keys and ciphertexts
  - Complete Subtree (CS)
  - Subset Difference (SD)



Main Idea for History-Free Update

- R(H)IBE:
  - KGC (or a parent user) issues a long-term secret key sk_{ID} using msk (or $sk_{parent\text{-}ID}$).
  - KGC (or a parent user) broadcasts key update information ku_T which is computed by msk (or $sk_{parent\text{-}ID}$).
  - A (child) user can generate the decryption key $dk_{ID,T}$ from sk_{ID} and ku_T if he/she is not revoked at time T.
- Two situations are equivalent:
  - A user ID is not revoked at time T
  - The user can generate the decryption key $dk_{ID,T}$
- Re-define the key update algorithm

Main Idea for History-Free Update



- Previous syntax

$$(\mathsf{mpk}, \mathsf{msk}) \leftarrow \mathsf{Setup}(1^\lambda, N, \ell)$$

$$\mathsf{sk}_{\mathsf{ID}|_i} \leftarrow \mathsf{SKGen}(\mathsf{sk}_{\mathsf{ID}|_{i-1}}, \mathsf{st}_{\mathsf{ID}|_{i-1}}, \mathsf{ID}|_i)$$

$$\mathsf{ku}_{\mathsf{ID}|_{i-1},T} \leftarrow \mathsf{KeyUp}(\mathsf{sk}_{\mathsf{ID}|_{i-1}}, \mathsf{ku}_{\mathsf{ID}|_{i-2},T}, \mathsf{st}_{\mathsf{ID}|_{i-1}}, RL_{\mathsf{ID}|_{i-1}})$$

$$\mathsf{dk}_{\mathsf{ID}|_i,T} \leftarrow \mathsf{DKGen}(\mathsf{sk}_{\mathsf{ID}|_i}, \mathsf{ku}_{\mathsf{ID}|_{i-1},T})$$

- Our modification

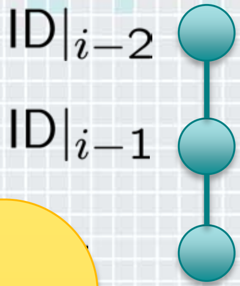
$$\mathsf{sk}_{\mathsf{ID}|_i} \leftarrow \mathsf{SKGen}(\mathsf{st}_{\mathsf{ID}|_{i-1}}, \mathsf{ID}|_i)$$

$$\mathsf{ku}_{\mathsf{ID}|_{i-1},T} \leftarrow \mathsf{KeyUp}(\mathsf{dk}_{\mathsf{ID}|_{i-1},T}, \mathsf{st}_{\mathsf{ID}|_{i-1}}, RL_{\mathsf{ID}|_{i-1}})$$

No parent secret key is required
(for history-free approach)
State information takes a role of the
delegation key

dk is used instead of sk and ku

Main Idea for History-Free Update



- Previous syntax

$(\mathsf{mpk}, \mathsf{msk}) \leftarrow \mathsf{Setup}(1^\lambda, N, \ell)$

$\mathsf{sk}_{\mathsf{ID}|_i} \leftarrow \mathsf{S}$

$\mathsf{ku}_{\mathsf{ID}|_{i-1},T}$

$\mathsf{dk}_{\mathsf{ID}|_i,T} \leftarrow$

- Our mod

$\mathsf{sk}_{\mathsf{ID}|_i} \leftarrow$

$\mathsf{ku}_{\mathsf{ID}|_{i-1},T}$

The secret key is used only for generating the decryption key dk.

Low-level users do not need to know what ancestors did during key updates.

ired
n)
of the

dk is used instead of sk and ku

Proposed RHIBE Scheme (CS)

- Based on the BBG HIBE scheme
  - BBG HIBE (ID) + Boneh-Boyen IBE (Time)
  - Give a reduction to the BBG HIBE scheme.
    - [BBG05] Boneh, D., Boyen, X., Goh, E.-J.: Hierarchical identity based encryption with constant size ciphertext. EUROCRYPT 2005.

$$\mathsf{mpk} = \{N, g, h, u_1, \ldots, u_\ell, g_1, g_2, \underline{u', h'}\}$$

$$\mathsf{msk} = \{g_2^\alpha\}$$

(Boneh-Boyen hash)

$$\mathsf{sk}_{\mathsf{ID}|_k} = \left\{P_\theta (u_1^{I_1} \cdots u_k^{I_k} h)^{r_\theta},\ g^{r_\theta},\ u_{k+1}^{r_\theta}, \ldots, u_\ell^{r_\theta}\right\}_{\theta \in \mathsf{Path}(\mathsf{ID}|_k)}$$

$$\mathsf{ku}_{\mathsf{ID}|_{k-1},T} = \left\{P_\theta^{-1} \cdot g_2^\alpha (u_1^{I_1} \cdots u_k^{I_k} h)^{r_\theta} (u'^T h')^{t_\theta},\ g^{r_\theta},\ g^{t_\theta},\ u_k^{r_\theta}, \ldots, u_\ell^{r_\theta}\right\}_{\theta \in \mathsf{KUNode}(\mathsf{BT}_{\mathsf{ID}|_{k-1}}, RL_{\mathsf{ID}|_{k-1}}, T)}$$

$$\mathsf{dk}_{\mathsf{ID}|_k,T} = (g_2^\alpha (u_1^{I_1} \cdots u_k^{I_k} h)^r (u'^T h')^t, g^r, g^t, u_{k+1}^r, \ldots, u_\ell^r)$$

$$\mathsf{CT} = (\underline{M \cdot e(g_1, g_2)^s, g^s, (u_1^{I_1} \cdots u_k^{I_k} h)^s}, \underline{(u'^T h')^s})$$

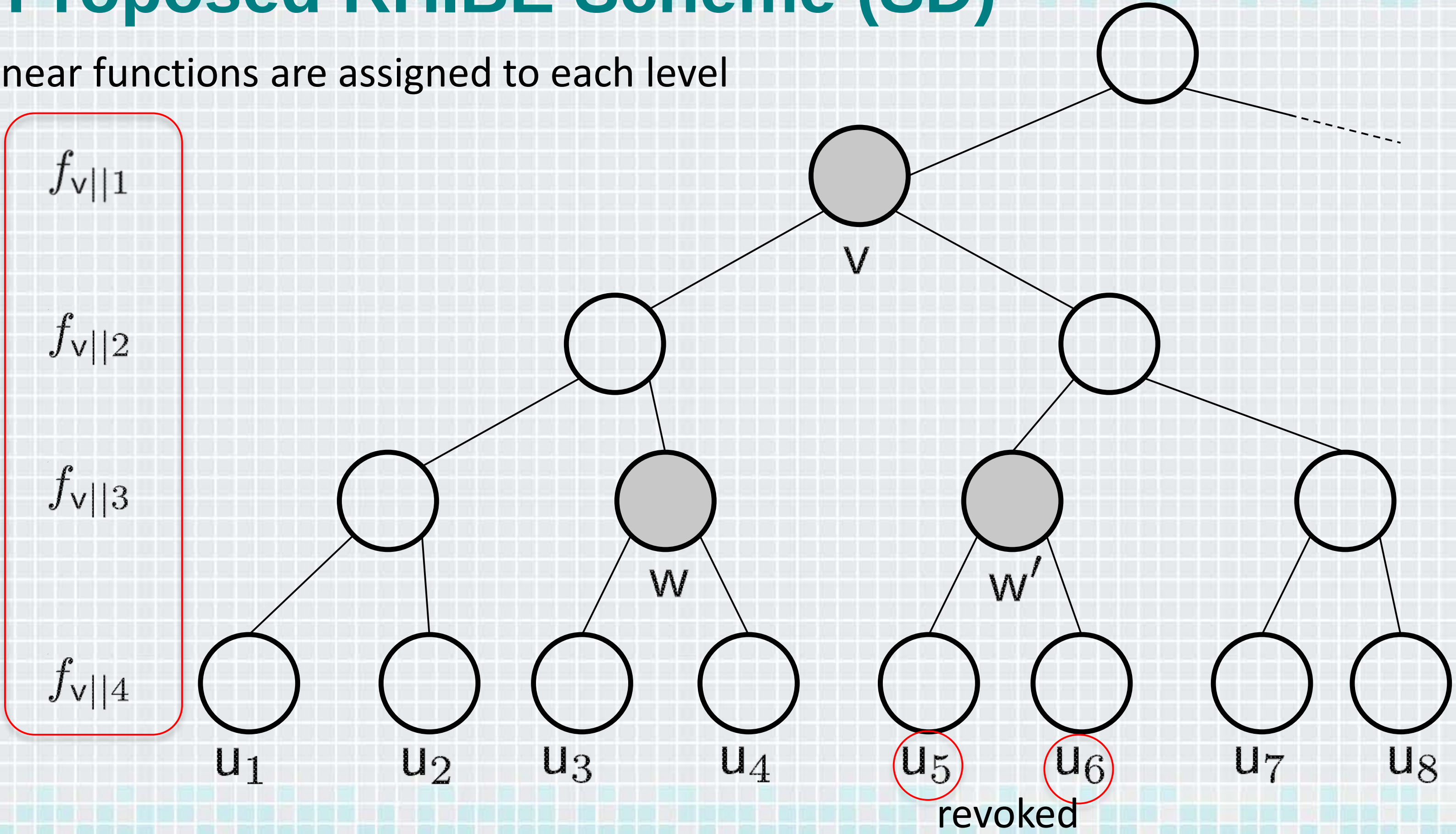
BBG HIBE (ID) — BB IBE (Time)

> If ID|$_k$ is not revoked, then there exists the same θ (CS method)

> With re-randomization for decryption key exposure resistance

Proposed RHIBE Scheme (SD)

Linear functions are assigned to each level



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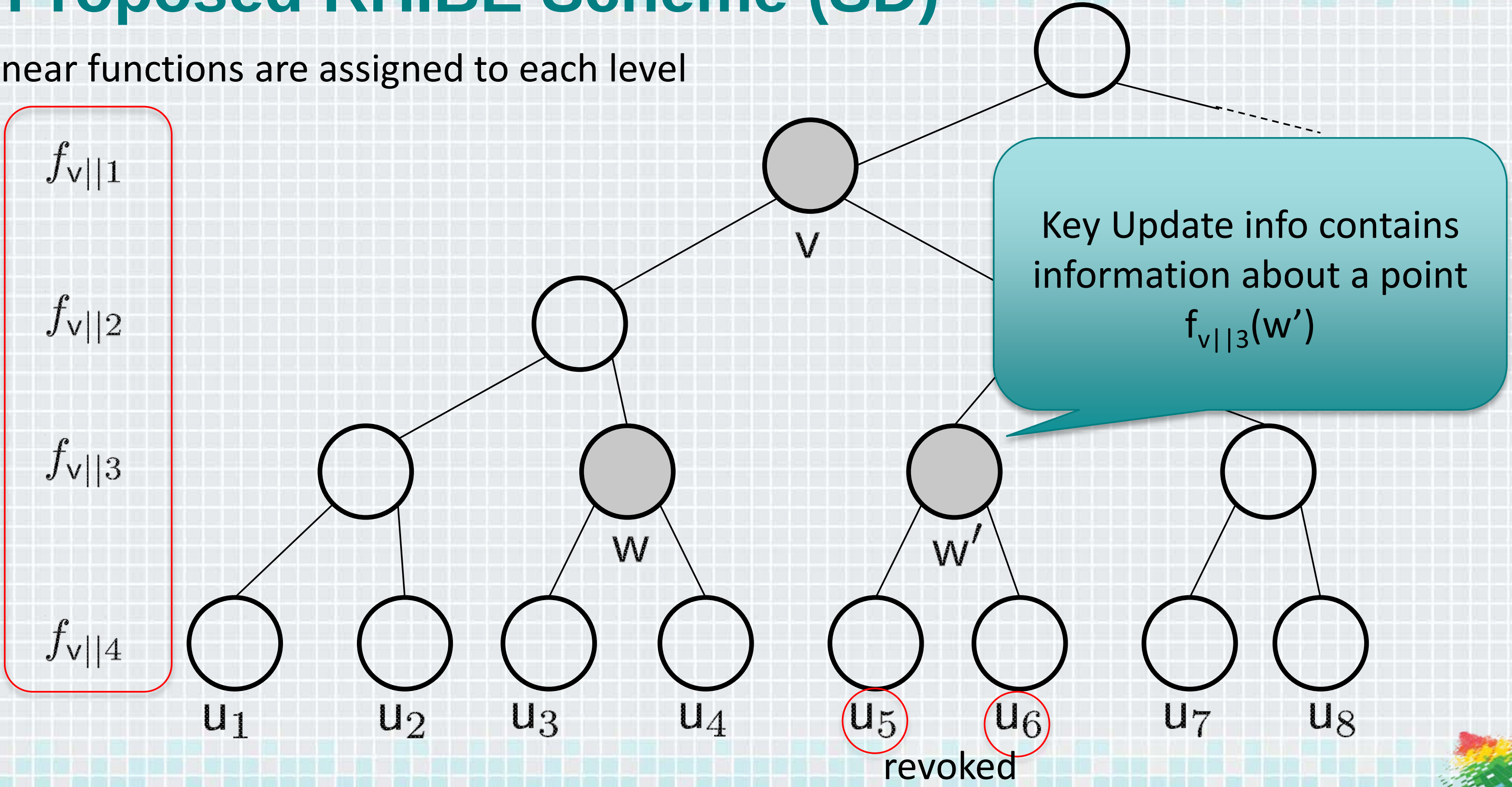

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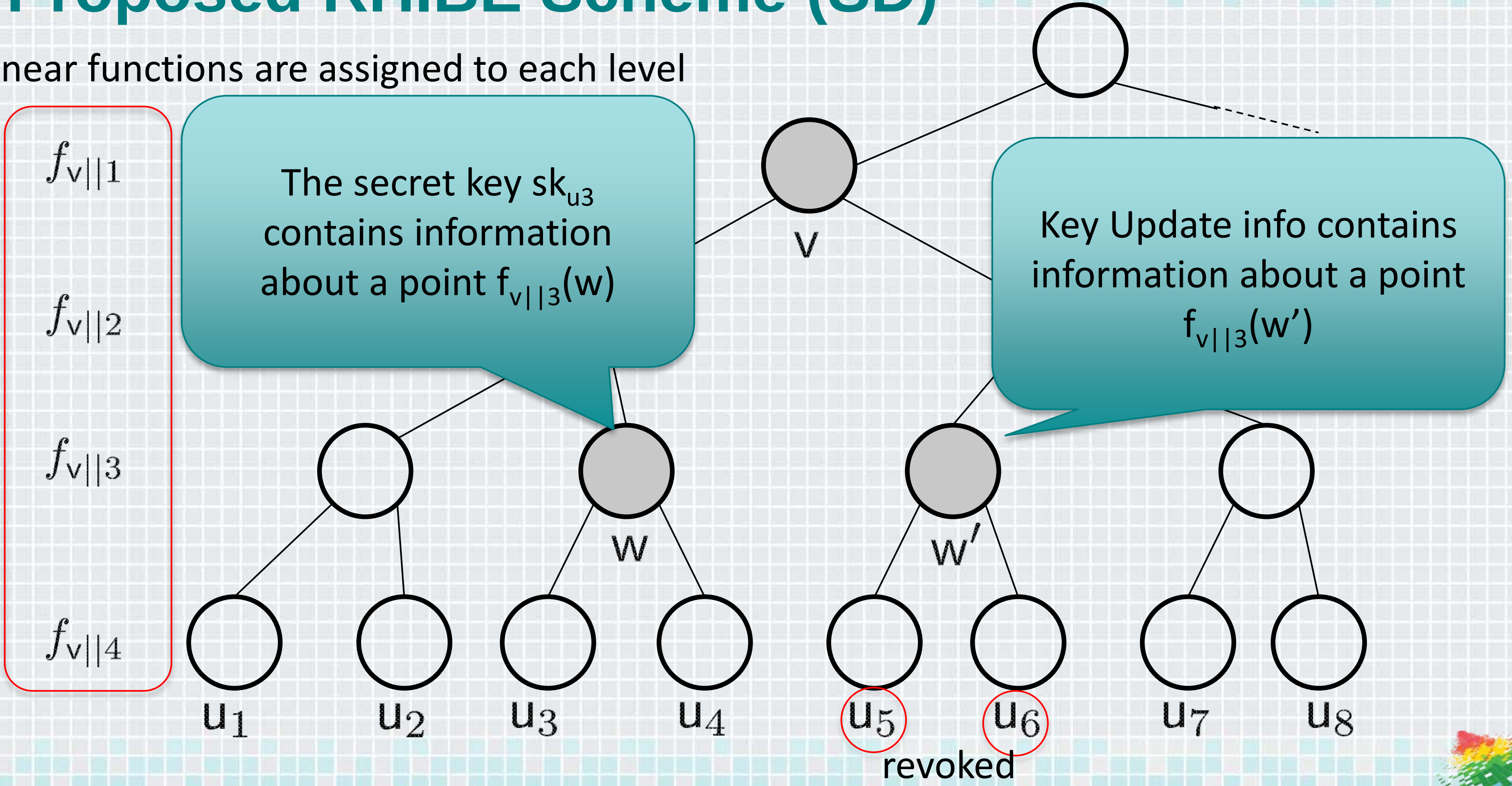

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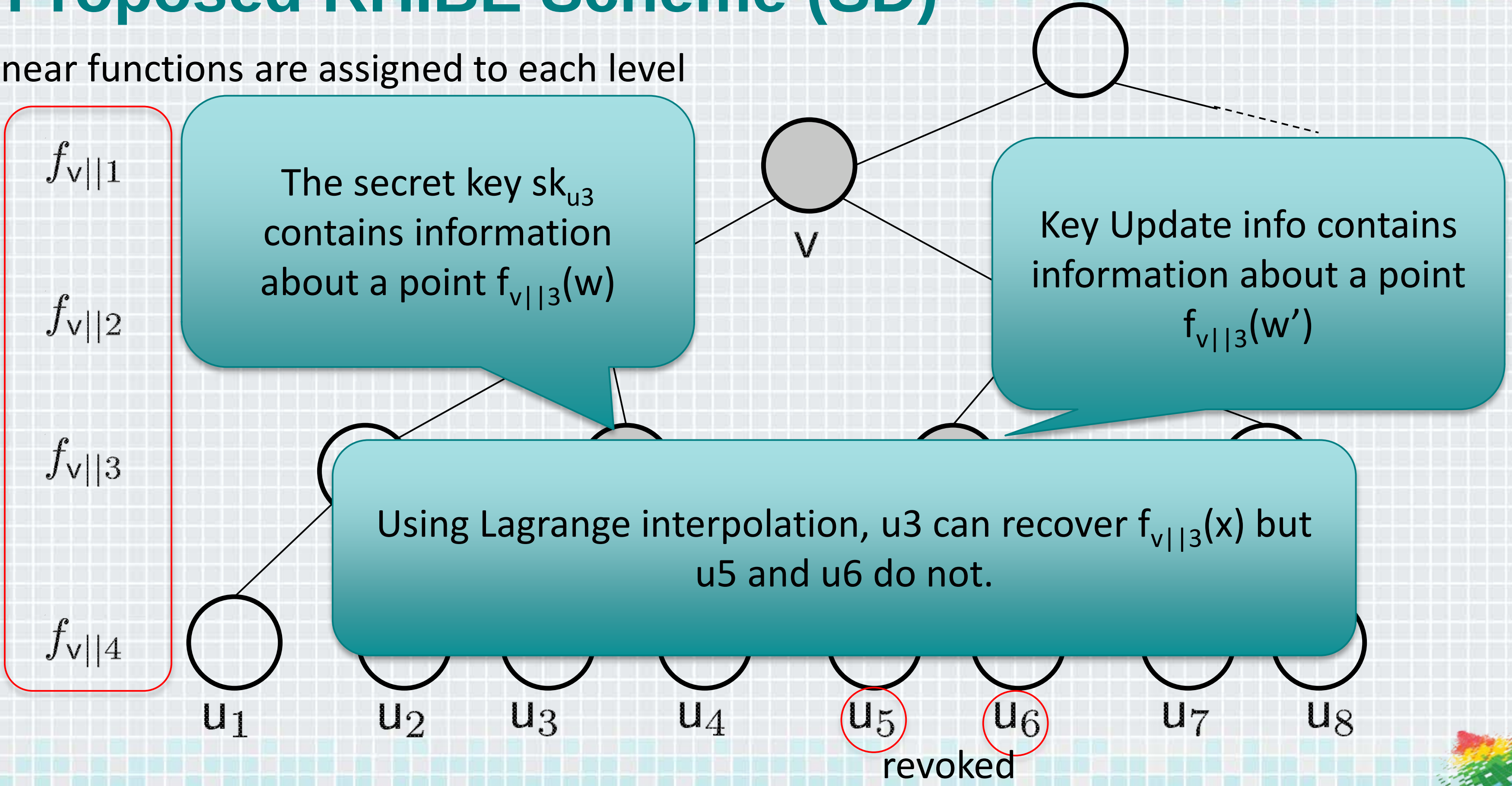

Proposed RHIBE Scheme (SD)

- The main part is the same as that of the LLP RIBE scheme.
  - K. Lee, D. H. Lee, and J. H. Park. Efficient revocable identity-based encryption via subset difference methods, eprint.iacr.org/2014/132, 2014.
- One difference is: we introduce the false master key for history-free construction so that sk does not contain the master key α

$$f_y(x) := \mathsf{PRF}_k(y)x + \beta$$

See the paper for details

Comparison

Table 1: Revocable Hierarchical Identity-Based Encryption schemes

	SK size	CT size	KU size	Model	Sec. ag. insiders	DKE resist.	Assum.
Trivial	$\omega(2^\ell)$						
SE13	$O(\ell^2 \log N)$	$O(\ell)$	$O(r \log \frac{N}{r})$	Std., Sel.	✘	✘	static
CS const.	$O(\ell \log N)$	$O(1)$	$O(\ell r \log \frac{N}{r})$	Std., Sel.	✔	✔	q-type
SD const.	$O(\ell (\log N)^2)$	$O(1)$	$O(\ell r)$	Std., Sel., SRL	✔	✔	q-type

Std.: standard model, Sel.: selective security, SRL: selective revocation list [BGK08,LLP14]

ℓ: maximum hierarchical level, N: maximum number of users in the system, r: number of revoked users.

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DBDH

q-weak Bilinear Diffie-Hellman Inversion

Conclusion and Future work

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- RHIBE:
  - History-free update, insider security, short ciphertext, and DKER
- The reduction to the underlying HIBE requires the challenge identity for the security proof.
  - Adaptive-ID secure RHIBE under a static assumption with these desirable properties