Self-Updatable Encryption: Time Constrained Access Control with Hidden Attributes and Better Efficiency

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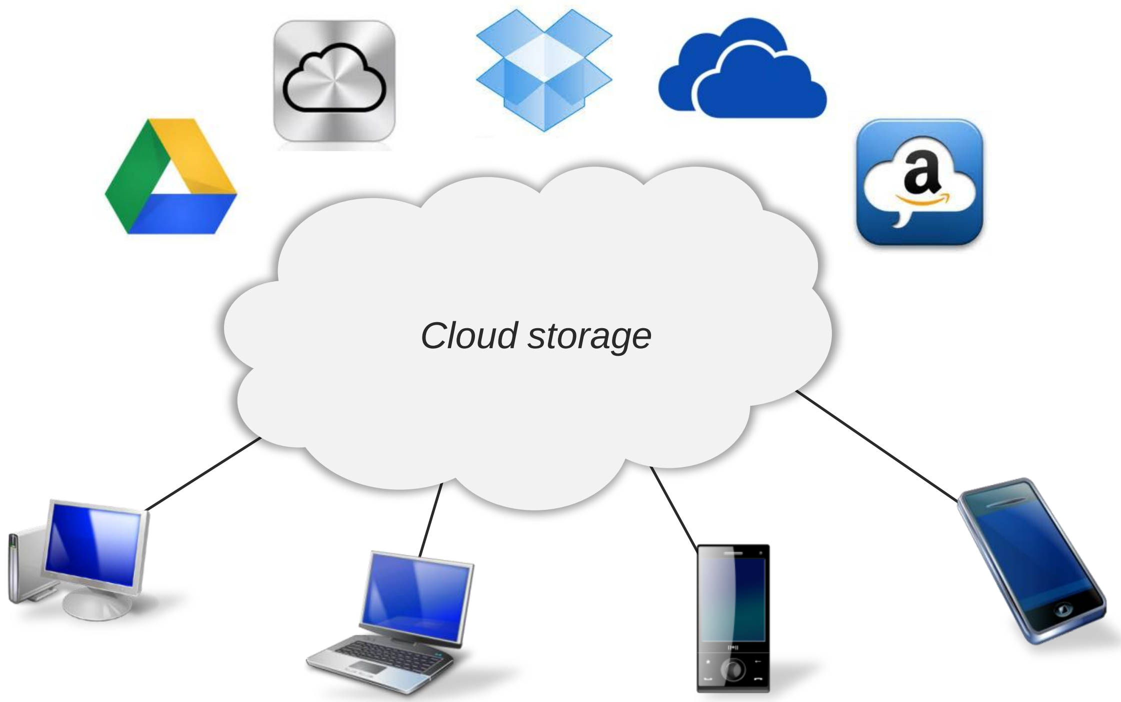
Overview

- Motivation
  - A revocable-storage attribute-based encryption (RS-ABE) is a good access control mechanism for cloud storage by supporting *key-revocation* and *ciphertext-update*
  - We ask whether it is possible to have a modular approach for RS-ABE by using a primitive for time-evolution mechanism

- Results
  - We introduce a *self-updatable encryption (SUE)* for a time evolution mechanism, and construct an efficient SUE scheme
  - We present a new *revocable-storage attribute-based encryption (RS-ABE)* scheme with shorter ciphertexts
  - We also obtain a *revocable-storage predicate encryption (RS-PE)* scheme that supports attribute-hiding property

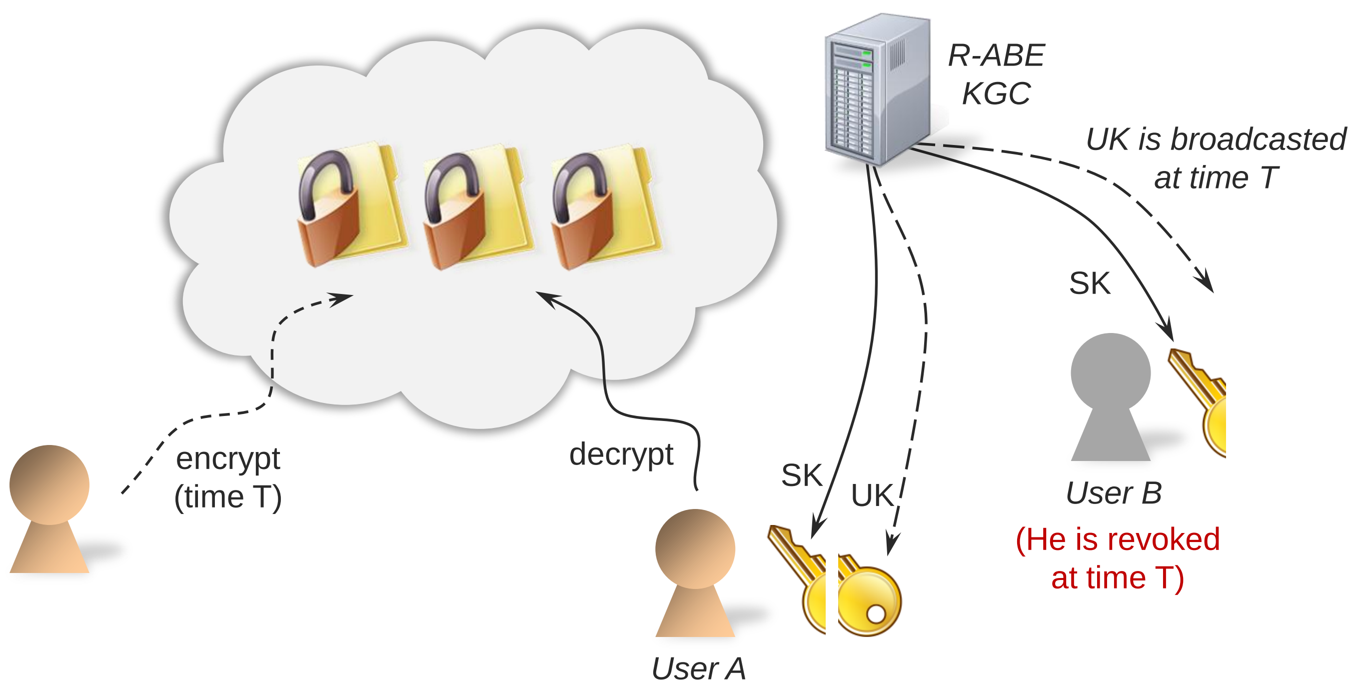
Introduction

- Cloud Storage
  - Cloud data storage has many advantages: A virtually unlimited amount of space can be allocated, and storage management can be easier
  - Moreover, it provides great accessibility: Users in any geographic location can access their data through the Internet



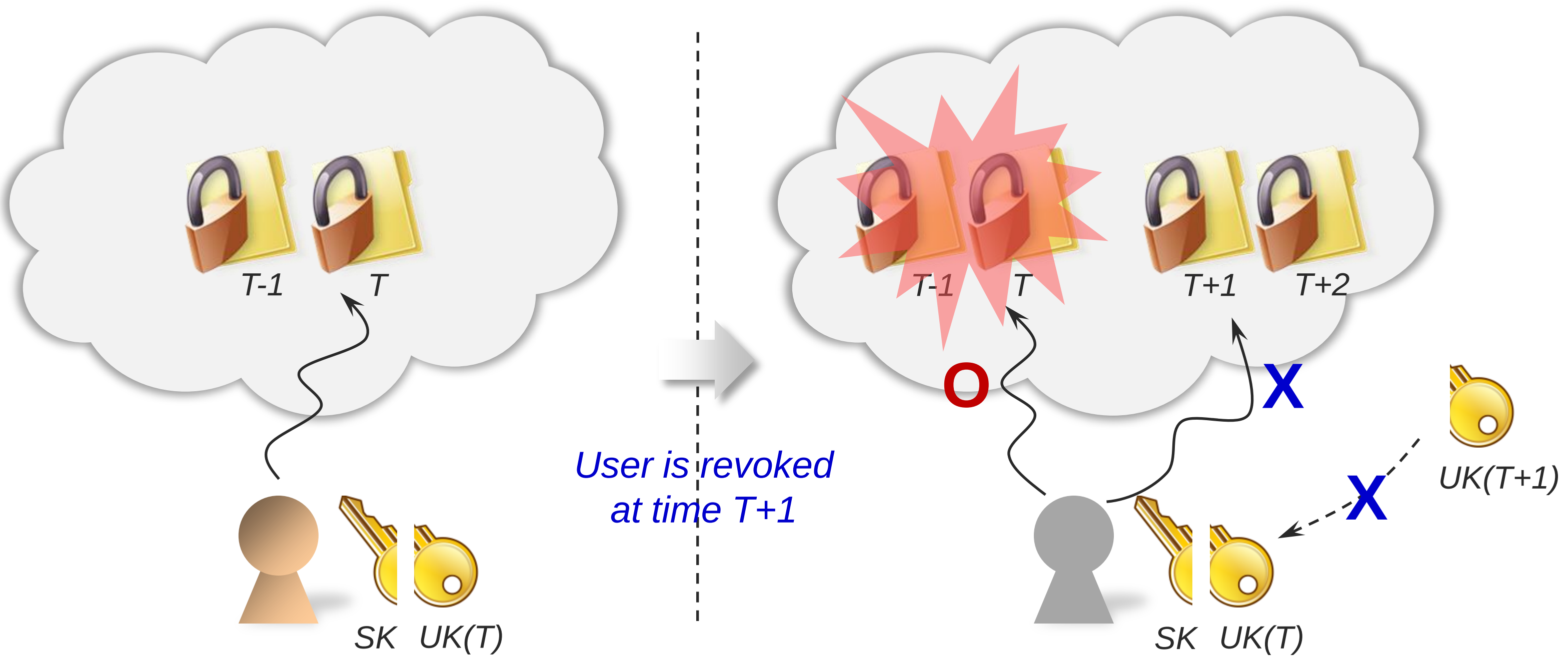
Introduction

- Access Control for Cloud Storage
  - Access control is one of greatest concerns: the senstive data should be protected from any illegal access from outsiders or from insiders
  - A revocable ABE (R-ABE) can be used for access control in cloud storage by revoking a user's private key if his credential is expired



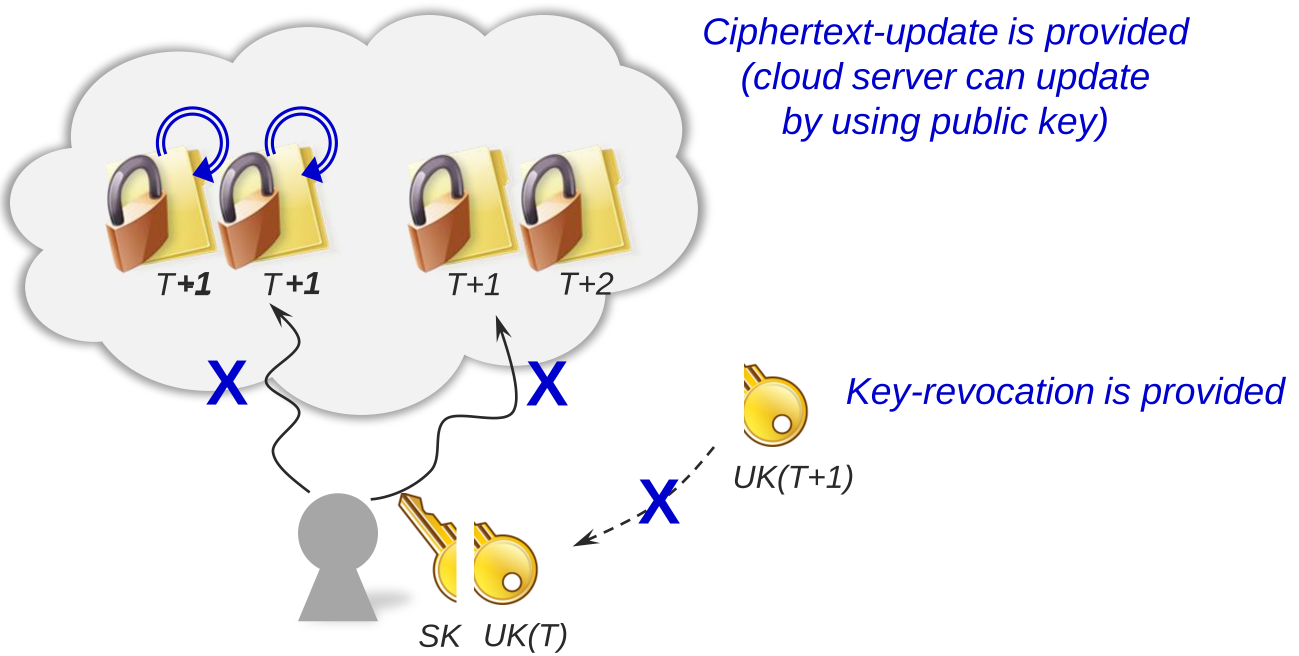
Introduction

- Novel Concern in Cloud Storage
  - Sahai, Seyalioglu, and Waters (Crypto 2012) pointed out that R-ABE alone does not suffice in managing dynamic credentials for cloud storage
  - R-ABE cannot prevent *a revoked user from accessing ciphertexts that were created before the revocation*, since the old private key is enough for decryption



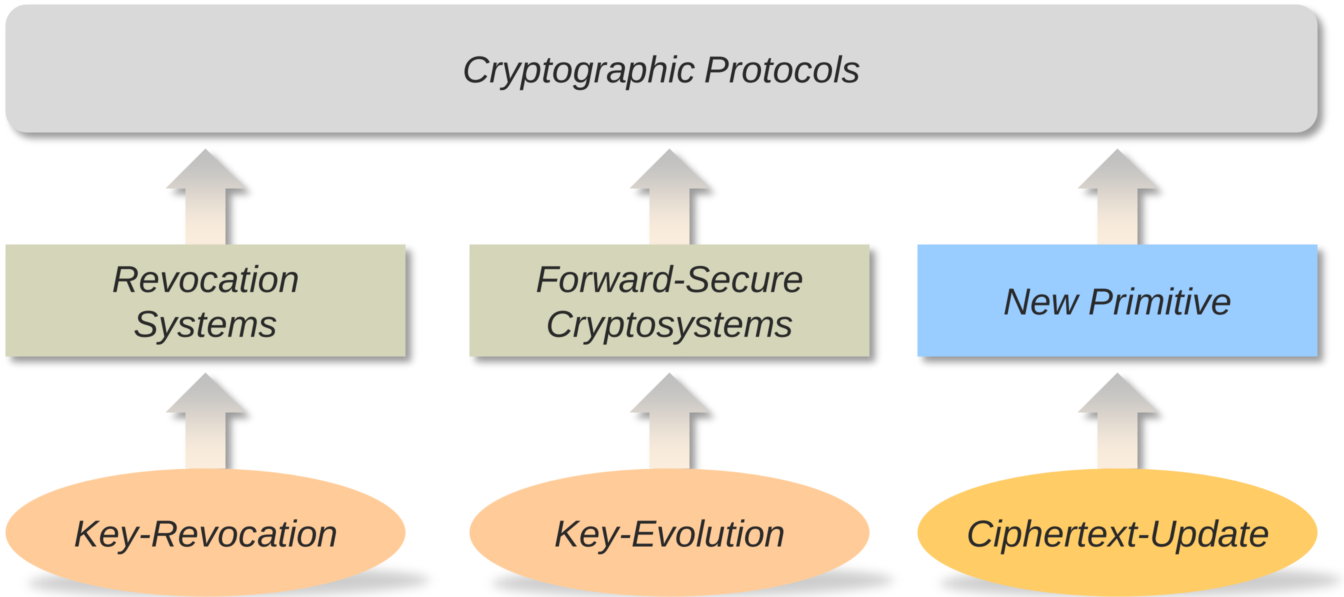
Introduction

- Revocable-Storage ABE
  - To solve the previous issue, Sahai et al. introduced a novel RS-ABE that supports not only *key-revocation* but also *ciphertext update*
  - That is, a ciphertext at any time *T* can be updated to a new ciphertext at time *T+1* by any party *just using the public key* (by the cloud server)



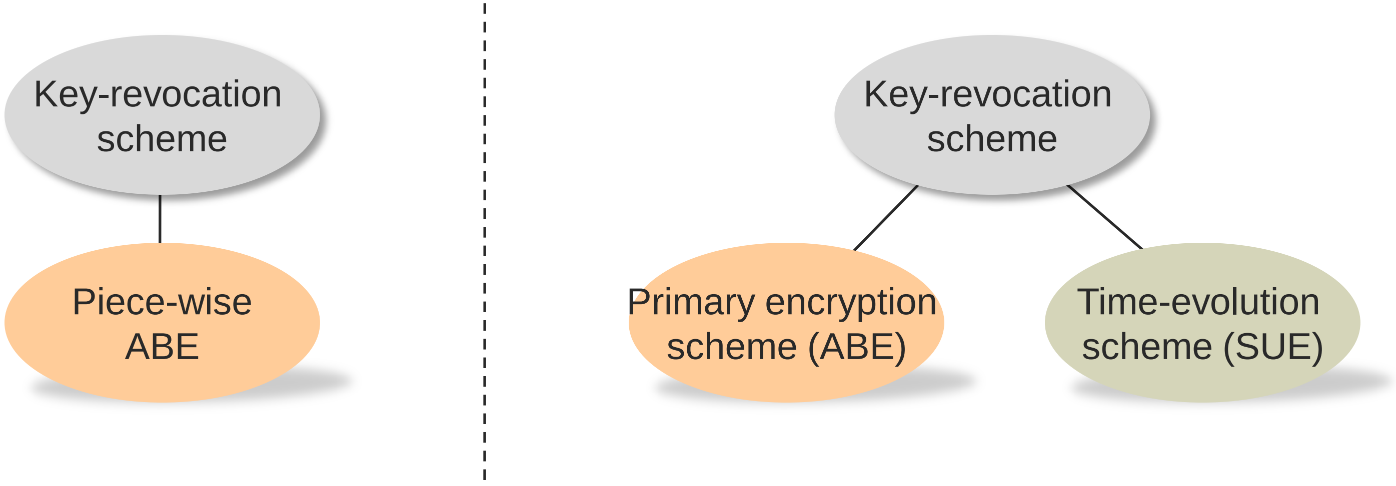
Introduction

- Our Motivation
  - Key-revocation and key-evolution are importance issues in cryptosystem design, and *ciphertext-update (time-evolution)* can be useful elsewhere
  - We want to achieve ciphertext-update (time-evolution) in other encryption scheme and use it as an underlying primitive



Introduction

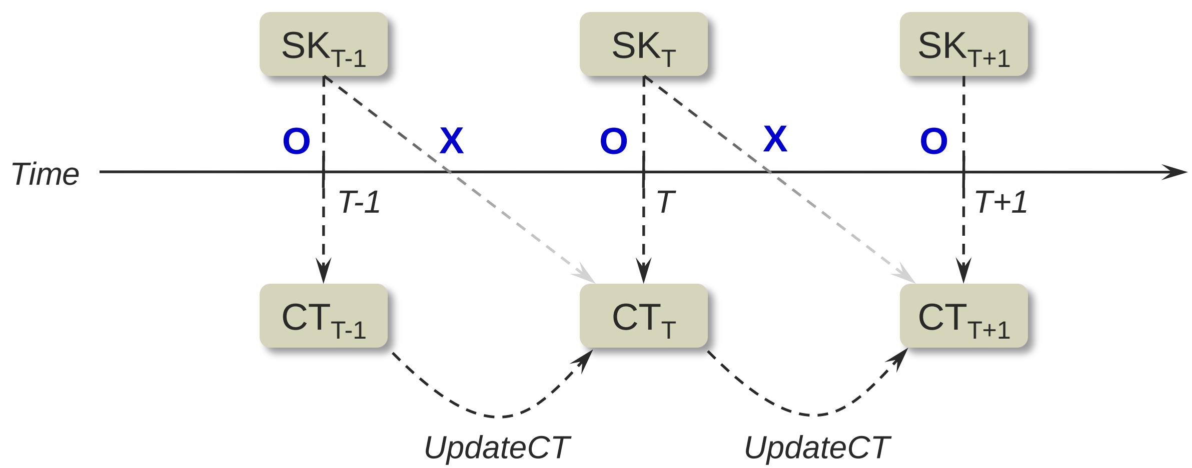
- Our Approach
  - We take a modular approach for RS-ABE by combining three components: a primary encryption scheme, a key-revocation mechanism, and a time-evolution mechanism
  - This approach has potential benefits since each mechanism may have independent interest and it may open the door to optimizations



The previous approach *Our modular approach*

Self-Updatable Encryption

- Overview
  - Self-updatable encryption (SUE) is a new cryptographic primitive that realizes a time-evolution mechanism
  - A private key and a ciphertext are associated with time T_k and T_c, and a private key for T_k can decrypt a ciphertext for T_c if $T_c \leq T_k$
  - Additionally, anyone can update a ciphertext with time T_c to a new ciphertext with new time T_c+1



Self-Updatable Encryption

- Definition
  - SUE is a new type of PKE with the ciphertext updating property (time-evolution mechanism)
  - An SUE scheme consists of algorithms: Setup, GenKey, Encrypt, UpdateCT, RandCT, and Decrypt

Setup(T_{max}) → MK,PP

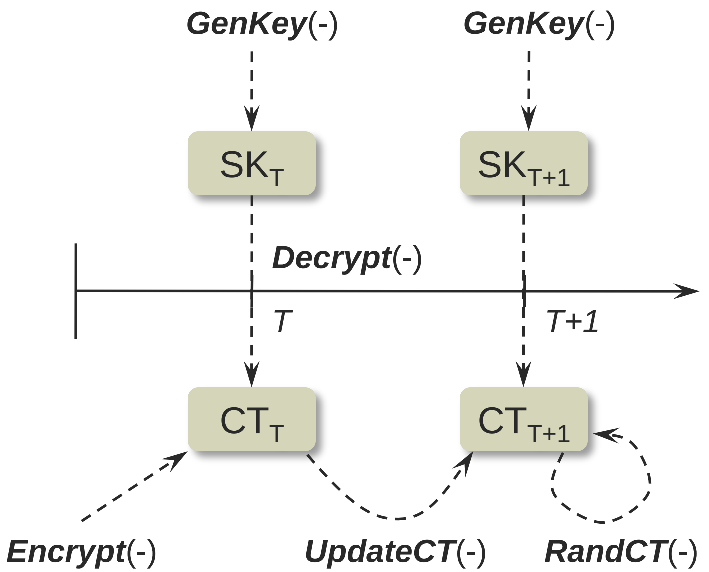
GenKey(T,MK,PP) → SK_T

Encrypt(T,M,PP) → CT_T

UpdateCT(CT_T,T+1,PP) → CT_{T+1}

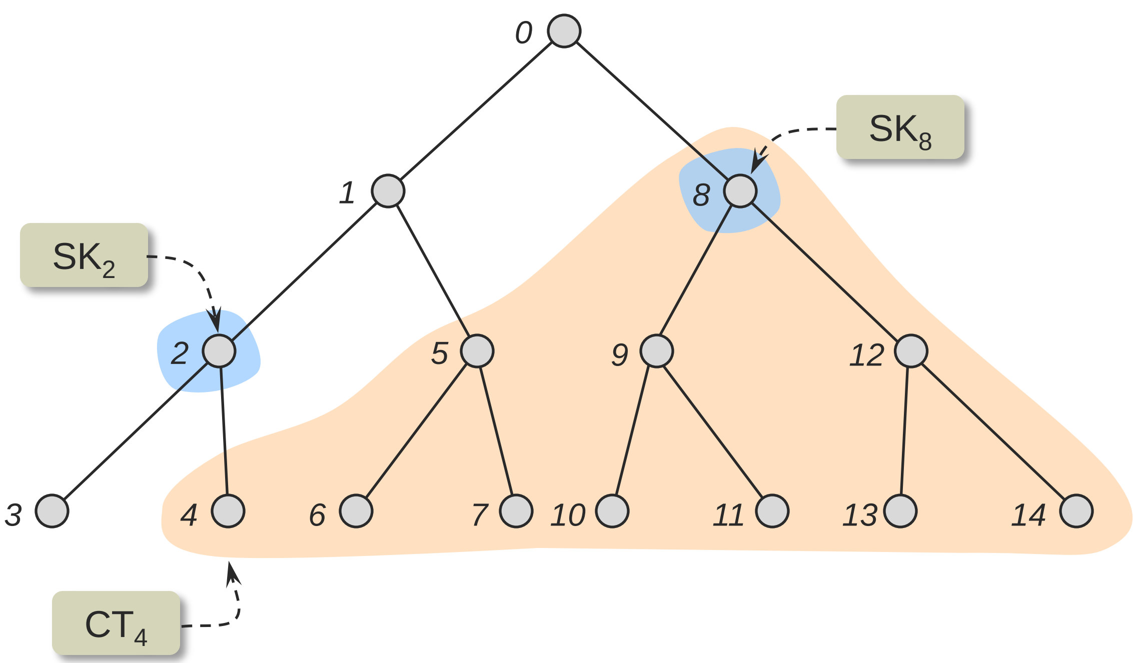
RandCT(CT_T,PP) → CT_T

Decrypt(CT_T,$SK_{T'}$,PP) → M



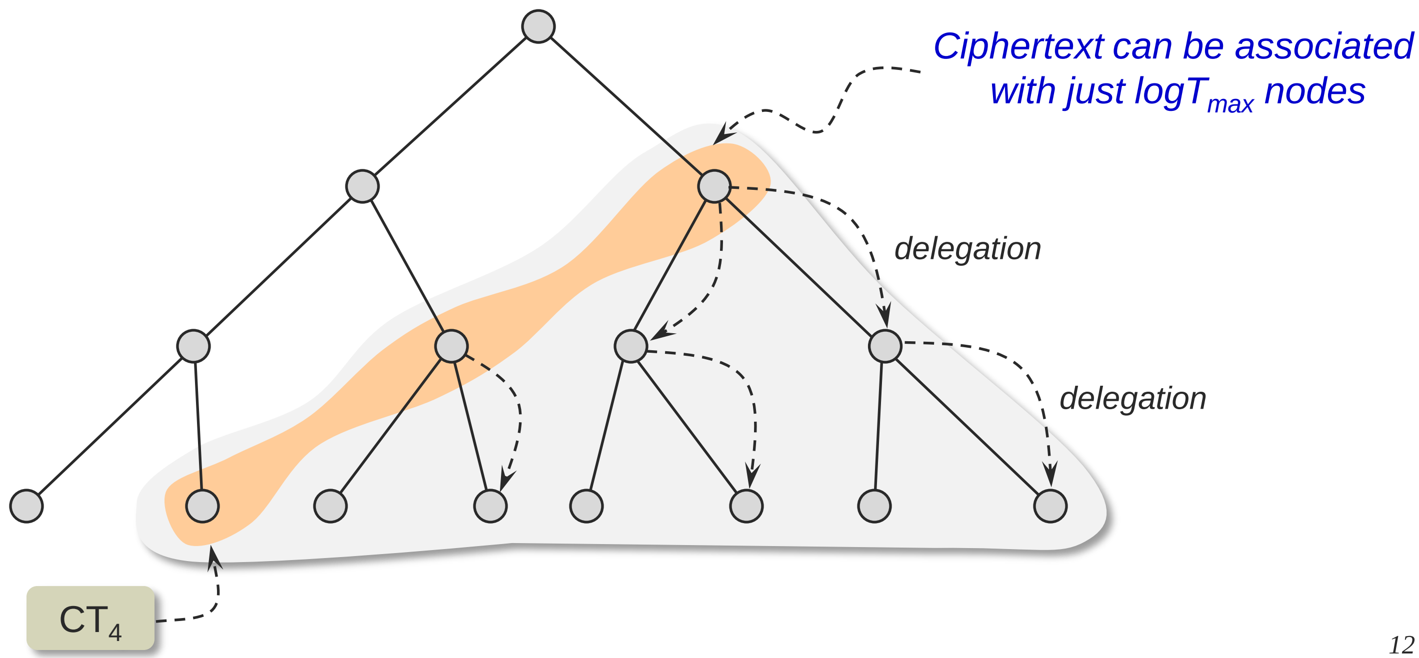
Self-Updatable Encryption

- Design Principle
  - A full binary tree is used to represent time by assigning time periods to tree nodes in pre-order traversal
  - A private key for time T_k is associated with a node v_k and a ciphertext for time T_c is associated with nodes $\{v_i\}$ for all time $T_i \geq T_c$



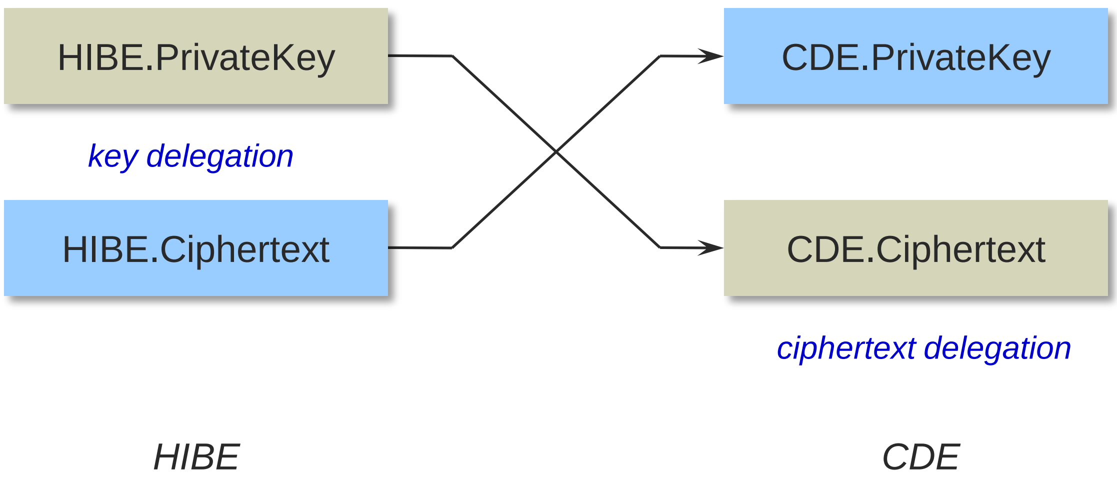
Self-Updatable Encryption

- Design Principle
  - If a ciphertext has *the delegation property* such that it's association can be changed from a node to it's chid node, then ciphertext can be shorten
  - The design idea of SUE is similar to that of forward-secure encryption, but ciphertexts are delegated in SUE (not private keys)



Self-Updatable Encryption

- Ciphertext Delegatable Encryption
  - CDE is a new type of PKE that has the ciphertext delegation property, and it can be used to build an SUE scheme
  - A CDE scheme could be derived from an HIBE scheme by switching the structure of private keys and that of ciphertexts



Self-Updatable Encryption

- Ciphertext Delegatable Encryption
  - We start from the HIBE scheme of Boneh and Boyen (Eurocrypt 2004) to derive a CDE scheme
  - The ciphertext delegation property of CDE could be obtained from the key delegation property of HIBE

BB_HIBE

$$SK = [g^{\beta} F_1(I_1)^{r_1}, g^{r_1}]$$

$$SK' = [g^{\beta} F_1(I_1)^{r_1} F_2(I_2)^{r_2}, g^{r_1}, g^{r_2}]$$

$$CT = [g^{s}, F_1(I_1)^{s}, F_2(I_2)^{s}]$$

CDE

$$SK = [g^{\beta} w^{r}, g^{r}, F_1(L_1)^{r}, F_2(L_2)^{r}]$$

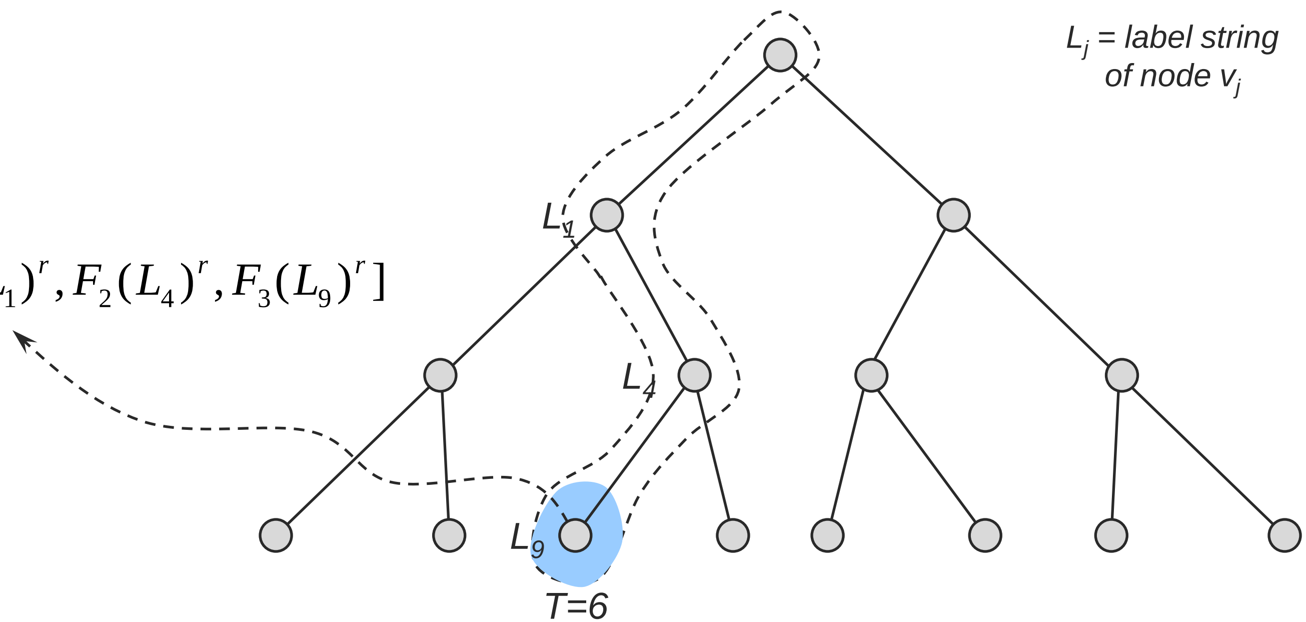
$$CT = [g^{s}, w^{s} F_1(L_1)^{s_1}, g^{s_1}]$$

$$CT' = [g^{s}, w^{s} F_1(L_1)^{s_1} F_2(L_2)^{s_2}, g^{s_1}, g^{s_2}]$$

Self-Updatable Encryption

- SUE Construction
  - $SK_T \leftarrow$ **GenKey**(T, MK, PP): The private key of SUE for time T is associated with path nodes Path(v) from the root node to a tree node v where v is associated with T

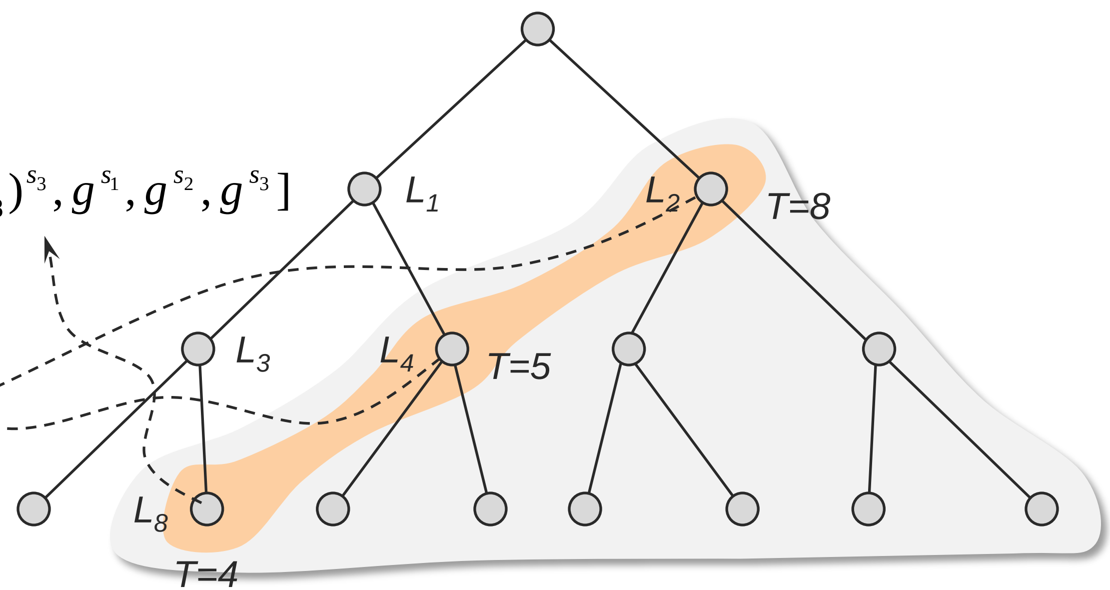
$$SK_6 =$$
$$[g^{\beta} w^{r}, g^{r}, F_1(L_1)^{r}, F_2(L_4)^{r}, F_3(L_9)^{r}]$$



Self-Updatable Encryption

- SUE Construction
  - CT_T←**Encrypt**(T, PP): The ciphertext of SUE for time T consists of ciphertexts of CDE for root nodes of all subtrees that cover all time $T_i \geq T$
  - The number of group elements in SUE can be reduced from $O(\log^2 T_{max})$ to $O(\log T_{max})$ by carefully reusing the randomness of CDE

$$CT_4 =$$
$$[g^s, w^s F_1(L_1)^{s_1} F_2(L_3)^{s_2} F_3(L_8)^{s_3}, g^{s_1}, g^{s_2}, g^{s_3}]$$
$$[g^s, w^s F_1(L_1)^{s_1} F_2(L_4)^{s'_2}, g^{s'_2}]$$
$$[g^s, w^s F_1(L_2)^{s'_1}, g^{s'_1}]$$

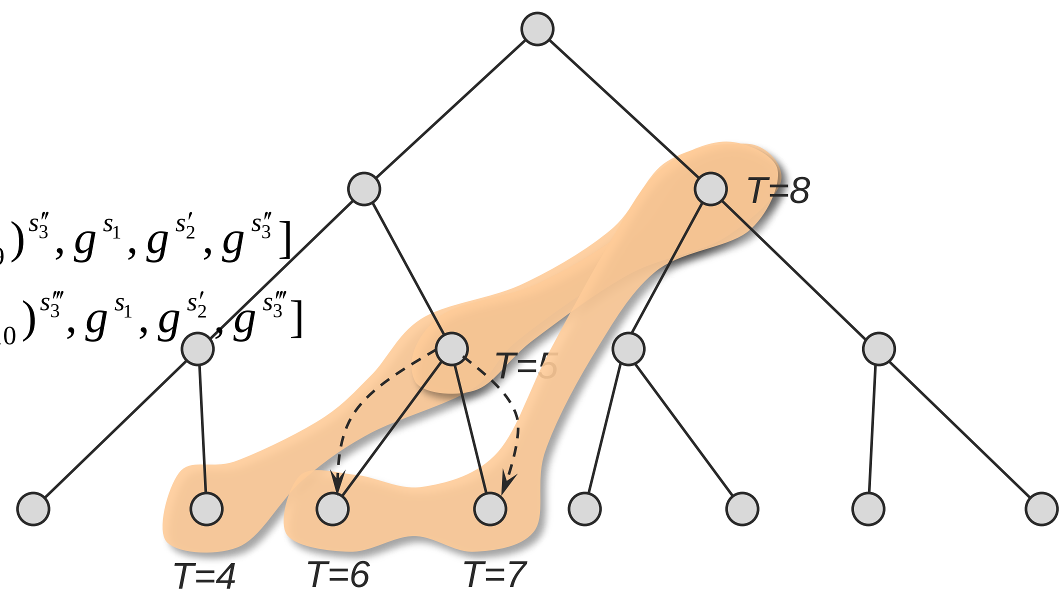


Self-Updatable Encryption

- SUE Construction
  - CT_{T+1}←**UpdateCT**(CT_T, $T+1$, PP): The ciphertext of SUE can be updated to next time by using the ciphertext delegation algorithm of CDE

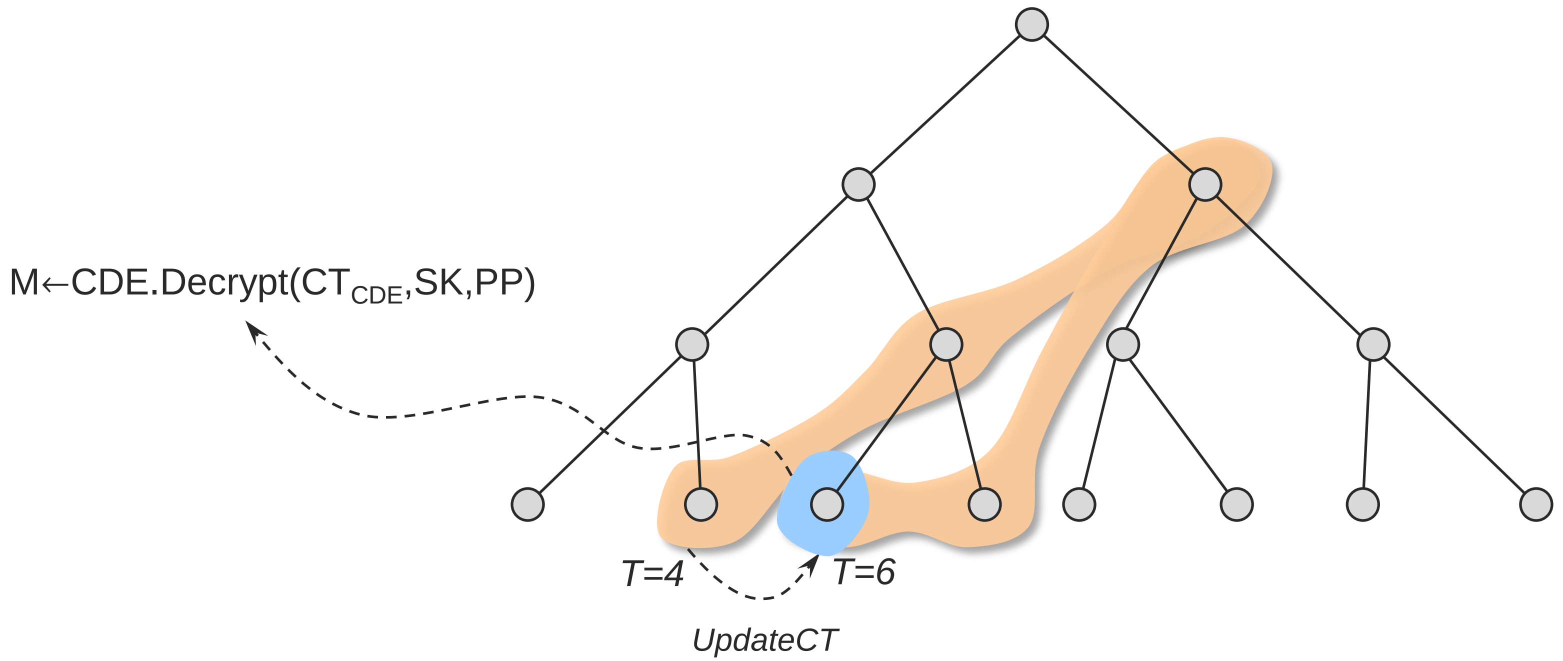
$$CT_5 =$$
$$[g^{s}, w^{s} F_1(L_1)^{s_1} F_2(L_4)^{s'_2}, g^{s_1}, g^{s'_2}]$$
$$[g^{s}, w^{s} F_1(L_2)^{s'_1}, g^{s'_1}]$$

$$CT_6 =$$
$$[g^{s}, w^{s} F_1(L_1)^{s_1} F_2(L_4)^{s'_2} F_3(L_9)^{s''_3}, g^{s_1}, g^{s'_2}, g^{s''_3}]$$
$$[g^{s}, w^{s} F_1(L_1)^{s_1} F_2(L_4)^{s'_2} F_3(L_{10})^{s'''_3}, g^{s_1}, g^{s'_2}, g^{s'''_3}]$$
$$[g^{s}, w^{s} F_1(L_2)^{s'_1}, g^{s'_1}]$$



Self-Updatable Encryption

- SUE Construction
  - $M \leftarrow$ **Decrypt**$(CT_T, SK_{T'}, PP)$: If $T \leq T'$, then a CDE ciphertext in SUE ciphertext can be decrypted by using the decryption algorithm of CDE



Self-Updatable Encryption

- Discussions
  - **Efficiency**: The number of group elements in *SK* is O(logT_{max}) and the number of group elements in *CT* is O(logT_{max})
  - **Exponential Number of Time Periods**: Our SUE scheme can support an exponential number (2^{λ}) of time periods by setting the tree depth to be the security parameter
  - **Time Interval**: By combining two SUE schemes (one for future SUE and another for past SUE), we expect to build an SUE scheme for time interval [T_L,T_R]
  - **Differenct Constructions**: We expect that different HIBE schemes will result different SUE schemes with different efficiency tradeoffs

Revocable-Storage ABE

- Definition
  - RS-ABE is an attribute-based encryption (ABE) that additionally supports both *key revocation* and *ciphertext update*
  - RS-ABE consits of algorithms: Setup, GenKey, UpdateKey, Encrypt, UpdateCT, RandCT, and Decrypt

Setup(…) → MK,PP

GenKey(S,u,MK,PP) → $SK_{S,u}$

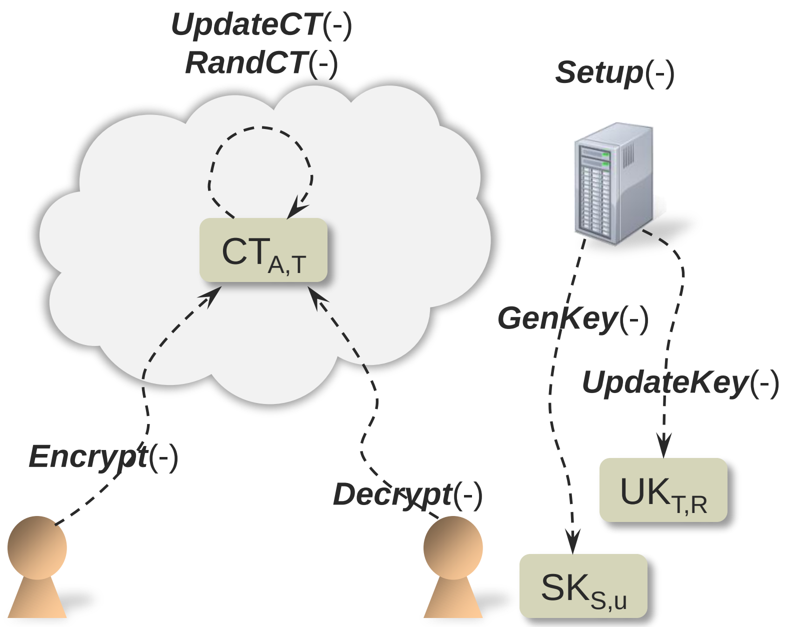
UpdateKey(T,R,MK,PP) → $UK_{T,R}$

Encrypt($\mathbb{A}$,T,M,PP) → $CT_{\mathbb{A},T}$

UpdateCT($CT_{\mathbb{A},T}$,T+1,PP) → $CT_{\mathbb{A},T+1}$

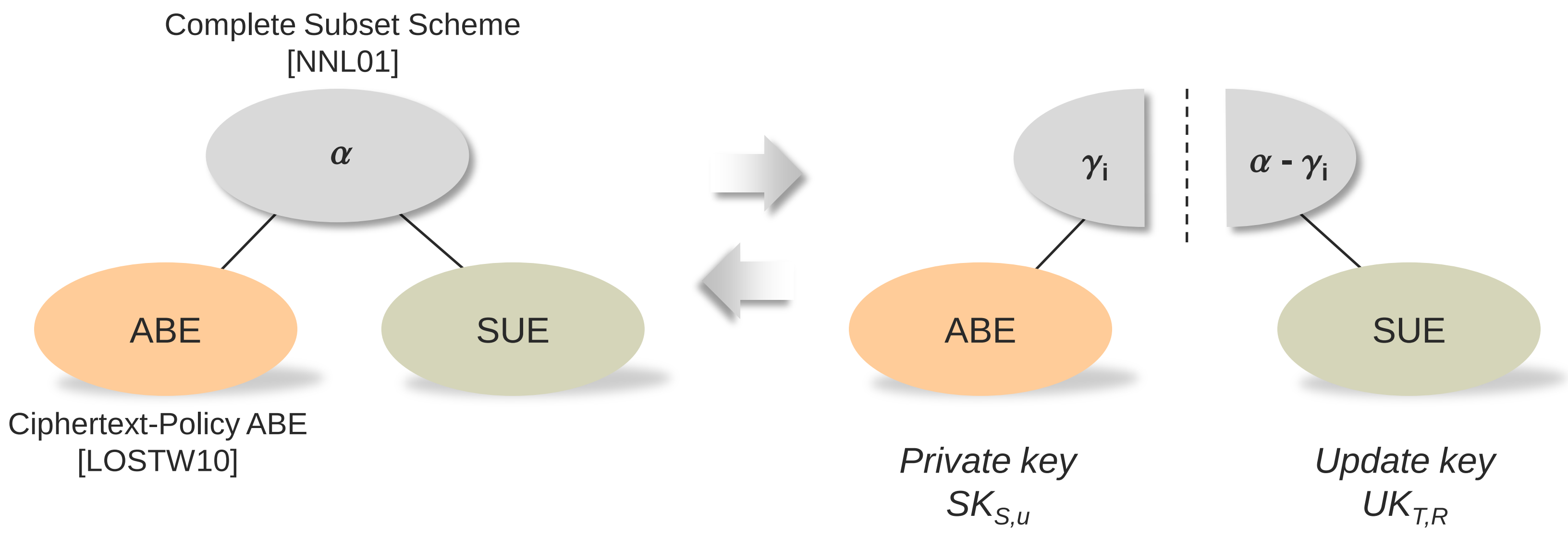
RandCT($CT_{\mathbb{A},T}$,PP) → $CT_{\mathbb{A},T}$

Decrypt($CT_{\mathbb{A},T}$,$SK_{S,u}$,$UK_{T',R}$,PP) → M



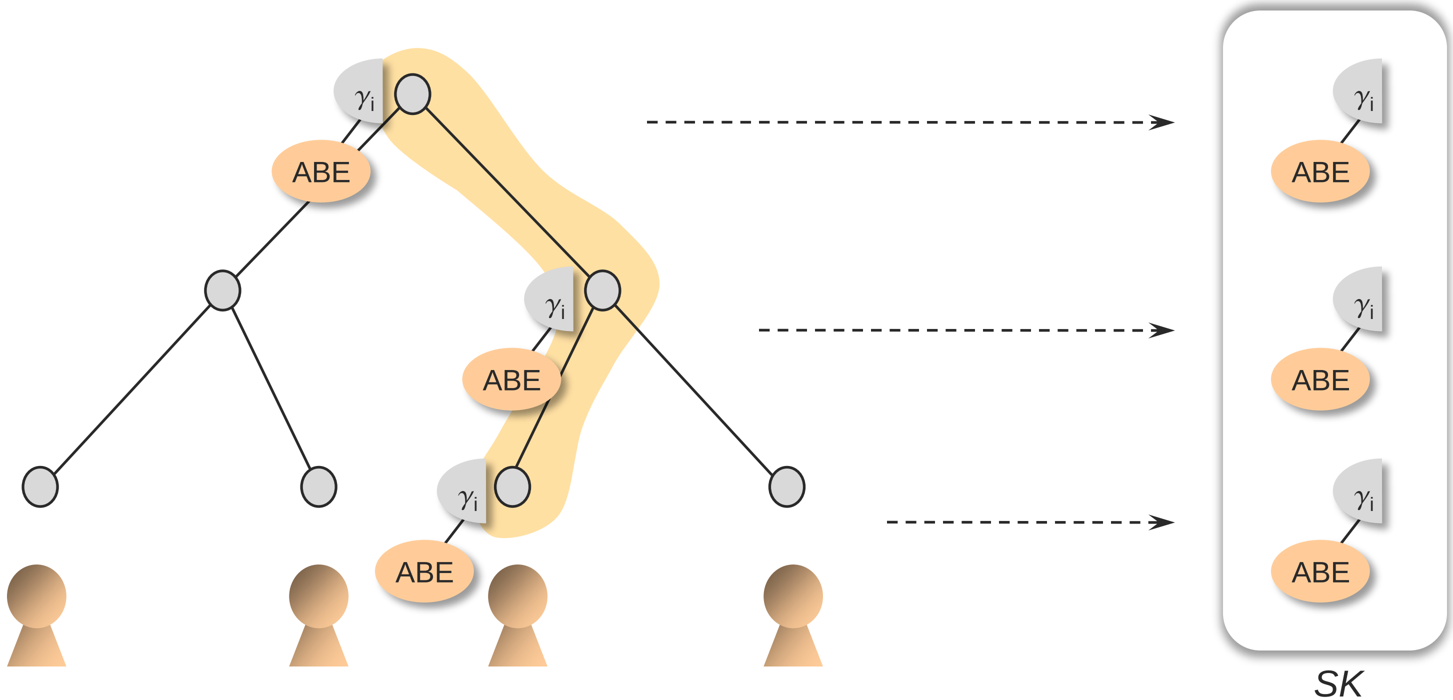
Revocable-Storage ABE

- Design Principle
  - Our scheme combines three components: a primary encryption scheme (CP-ABE), a key-revocation scheme, and a time-evolution scheme (SUE)
  - To prevent collusion-attacks, the key-revocation scheme uses a secret-sharing method when it combines two encryption components



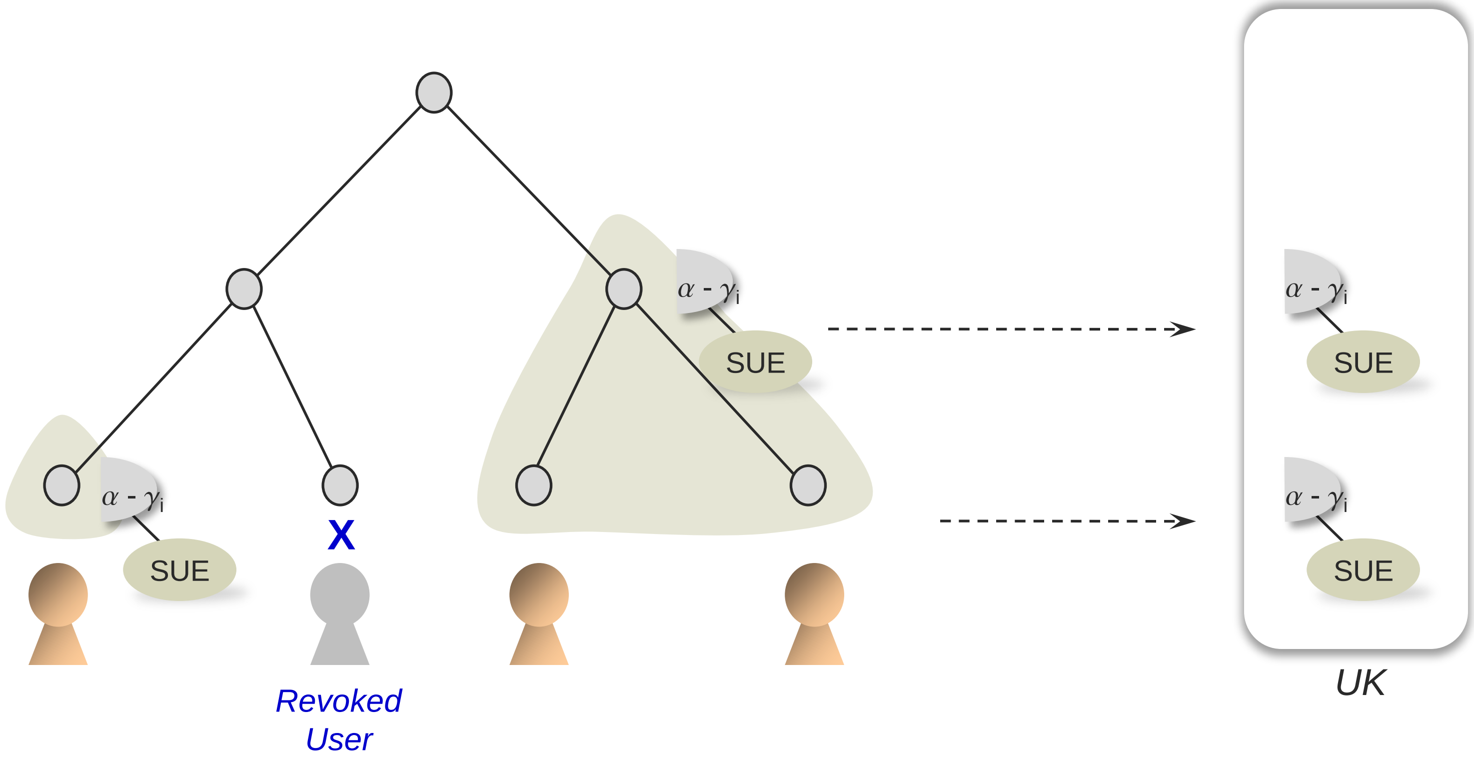
Revocable-Storage ABE

- RS-ABE Construction
  - **GenKey**: A private key (*SK*) consists of ABE private keys associated with path nodes of a user where the user is assigned to a leaf node of a binary tree of the CS scheme



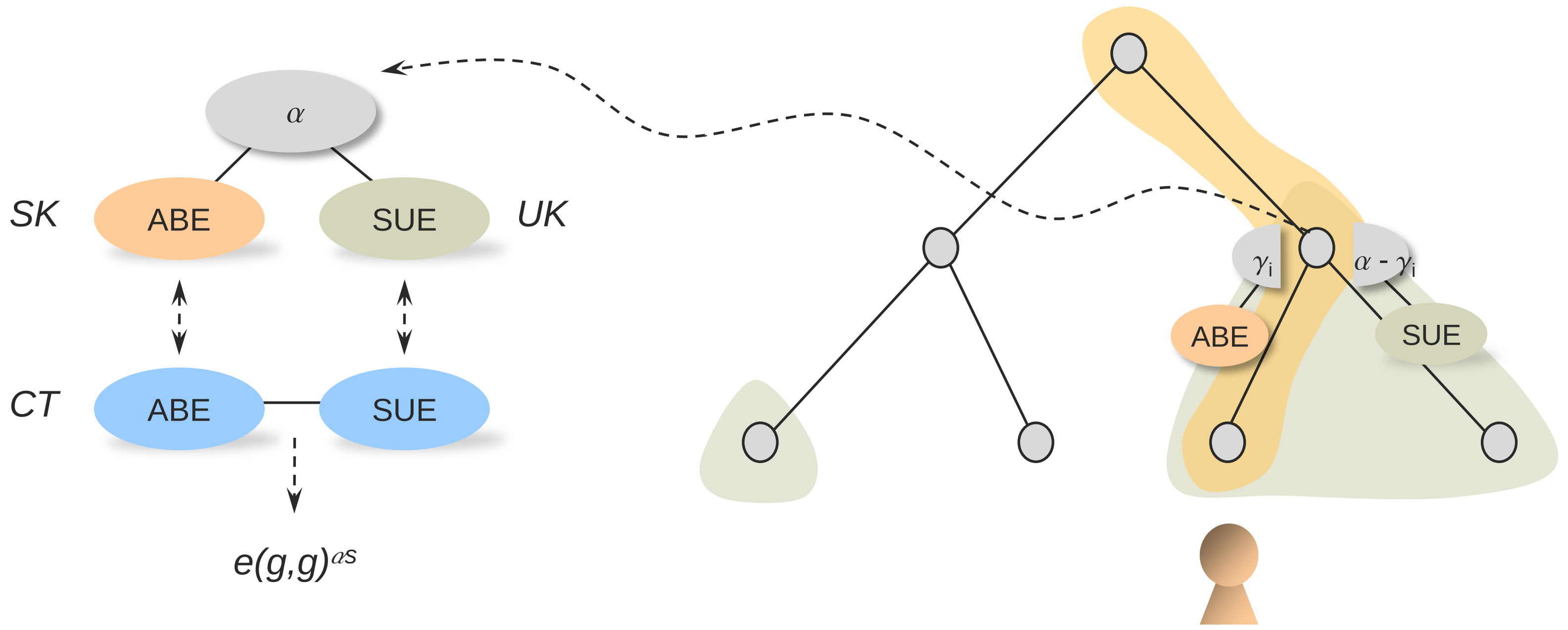
Revocable-Storage ABE

- RS-ABE Construction
  - **UpdateKey**: An update key (*UK*) consists of SUE private keys associated with covering subsets for non-revoked users (i.e. root nodes of subtrees that cover non-revoked users)



Revocable-Storage ABE

- RS-ABE Construction
  - **Encrypt**: A ciphertext (*CT*) consits of an SUE ciphertext and an ABE ciphertext with the same random exponent for secret sharing
  - **Decrypt**: If a user is not revoked ($u \notin R$) at time T, then a ciphertext with time T can be decrypted by an SUE private key from *SK* and an ABE private key from *UK*



Conclusion

- Other Applications
  - **Revocable-Storage Predicate Encryption** (RS-PE): By using an inner-product encryption (IPE) scheme as a primary encryption scheme, we can build an RS-PE scheme that provides *the attribute-hiding property* in ciphertexts
  - **Timed-Release Encryption** (TRE): TRE is a PKE such that a ciphertext with time T can be decrypted after T. An SUE scheme can be used to build a TRE scheme
  - **Key-Insulated Encryption** (KIE) with Ciphertext Forward Security: KIE is a PKE that provides tolerance against key exposures. By combining KIE and SUE schemes, we can build a KIE scheme with forward-secure storage

Thank You