Anonymous Public Key Encryption under Corruptions

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Background

- For PKE under corruptions, both the secret keys and messages could be leaked.
- The first notion of anonymity for PKE under corruptions (ANON-COR security) is proposed by Benhamouda et al. [BGG+20, TCC].
- In [BGG+20, TCC], ANON-COR secure and RSO secure PKE is employed to build an Evolving-Committee proactive secret sharing (ECPSS) Scheme.

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Unfortunately …

- No known PKE achieves ANON-COR security
- Non-adaptive: the adversary is *not* allowed to obtain any sk *before* seeing ct
- Single-challenge: each pk is used to encrypt a single message

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Unfortunately …

- No known PKE achieves ANON-COR security
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- Si

- Confidentiality: RSO security [HPW15] ($\mathcal{A}$ is able to open a specified subset of the challenge ciphertexts)
- Anonymity: ANON-COR security ($\mathcal{A}$ is **not** able to specify some challenge ciphertexts and open them)

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Unfortunately …

- No known PKE achieves ANON-COR security
- Non-adaptive: the adversary is *not* allowed to obtain any sk *before* seeing ct
- Single-challenge: each pk is used to encrypt a single message
- ANON-COR and RSO are formalized under different types of corruptions

Our Contributions

- **Define ANON-RSO$_k$&C security for PKE**

  (ANON-RSO$_k$&C security: ANONymity under Receiver Selective Opening attacks (in the k-challenge setting) and adaptive user Corruptions)

- **Define SIM-RSO$_k$&C security for PKE**

  (SIM-RSO$_k$&C security: confidentiality under the same types of corruptions like ANON-RSOk&C security)

- **Show a framework of constructing PKE achieving both ANON-RSO$_k$&C-CCA and SIM-RSO$_k$&C-CCA security**

Definition: ANON-RSO$_k$&C-CPA security

Real Game

$pk_1, \cdots, pk_n$

$\mathcal{D}_{\mathrm{pk}}, (m_{j,\gamma})_{j\in[t],\gamma\in[k]}$

$(i_j)_{j\in[t]} \leftarrow \mathcal{D}_{\mathrm{pk}}$

$(c_{j,\gamma} \leftarrow \mathbf{Enc}(pk_{i_j}, m_{j,\gamma}))_{j\in[t],\gamma\in[k]}$

$(c_{j,\gamma})_{j\in[t],\gamma\in[k]}$

out

Return $((i_j, (m_{j,\gamma})_{\gamma\in[k]})_{j\in[t]}, \mathcal{D}_{\mathrm{pk}}, I_{\mathrm{cor}}, I_{\mathrm{op}}, out)$

Definition: ANON-RSO$_k$&C-CPA security

Real Game

$pk_1, \cdots, pk_n$ →

$\mathcal{O}_{\mathbf{cor}}(\cdot)$

$I_{\mathrm{cor}} = I_{\mathrm{cor}} \cup \{i\}$

← i

← sk_i

$(i_j)_{j\in[t]} \leftarrow \mathcal{D}_{\mathrm{pk}}$

← $\mathcal{D}_{\mathrm{pk}}, (m_{j,\gamma})_{j\in[t],\gamma\in[k]}$

$(c_{j,\gamma} \leftarrow \mathbf{Enc}(pk_{i_j}, m_{j,\gamma}))_{j\in[t],\gamma\in[k]}$

$(c_{j,\gamma})_{j\in[t],\gamma\in[k]}$ →

$\mathcal{O}_{\mathbf{cor}}(\cdot)$

$I_{\mathrm{cor}} = I_{\mathrm{cor}} \cup \{i\}$

← i

← sk_i

$\mathcal{O}_{\mathbf{open}}(\cdot)$

$I_{\mathrm{op}} = I_{\mathrm{op}} \cup \{j\}$

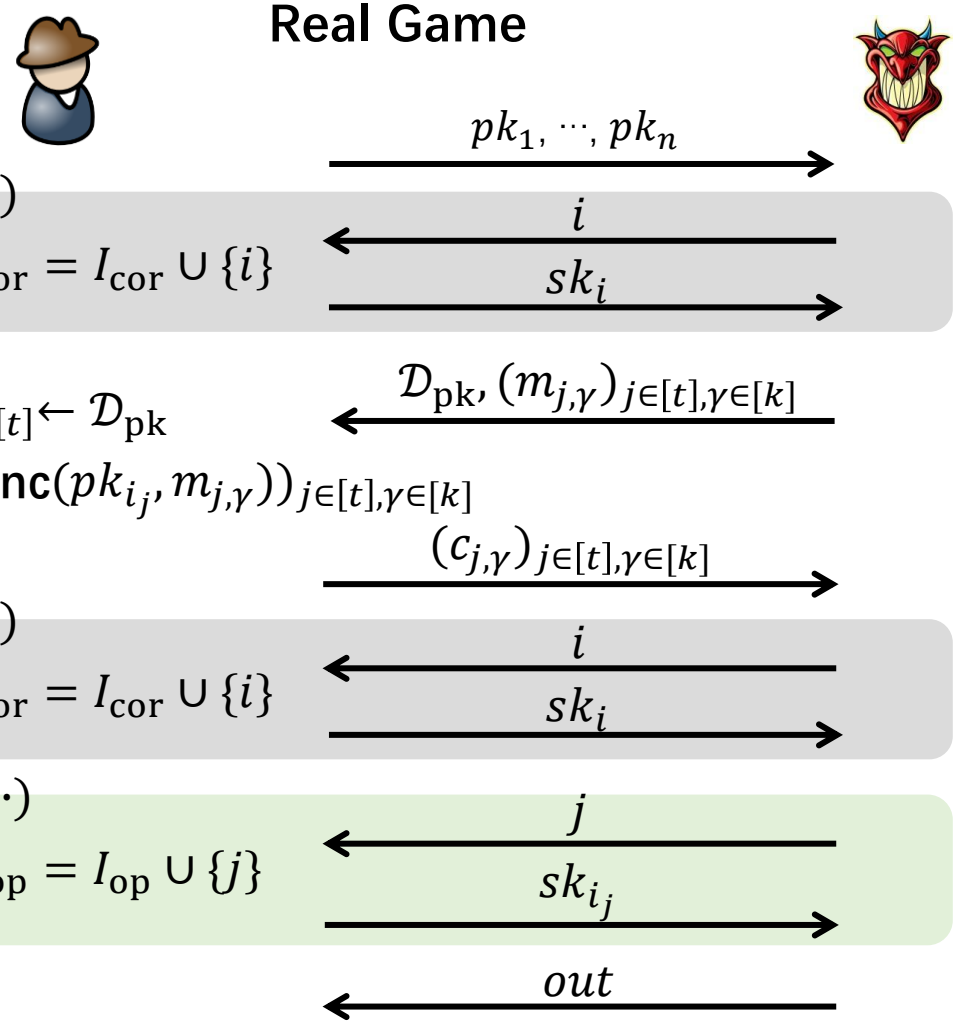
← j

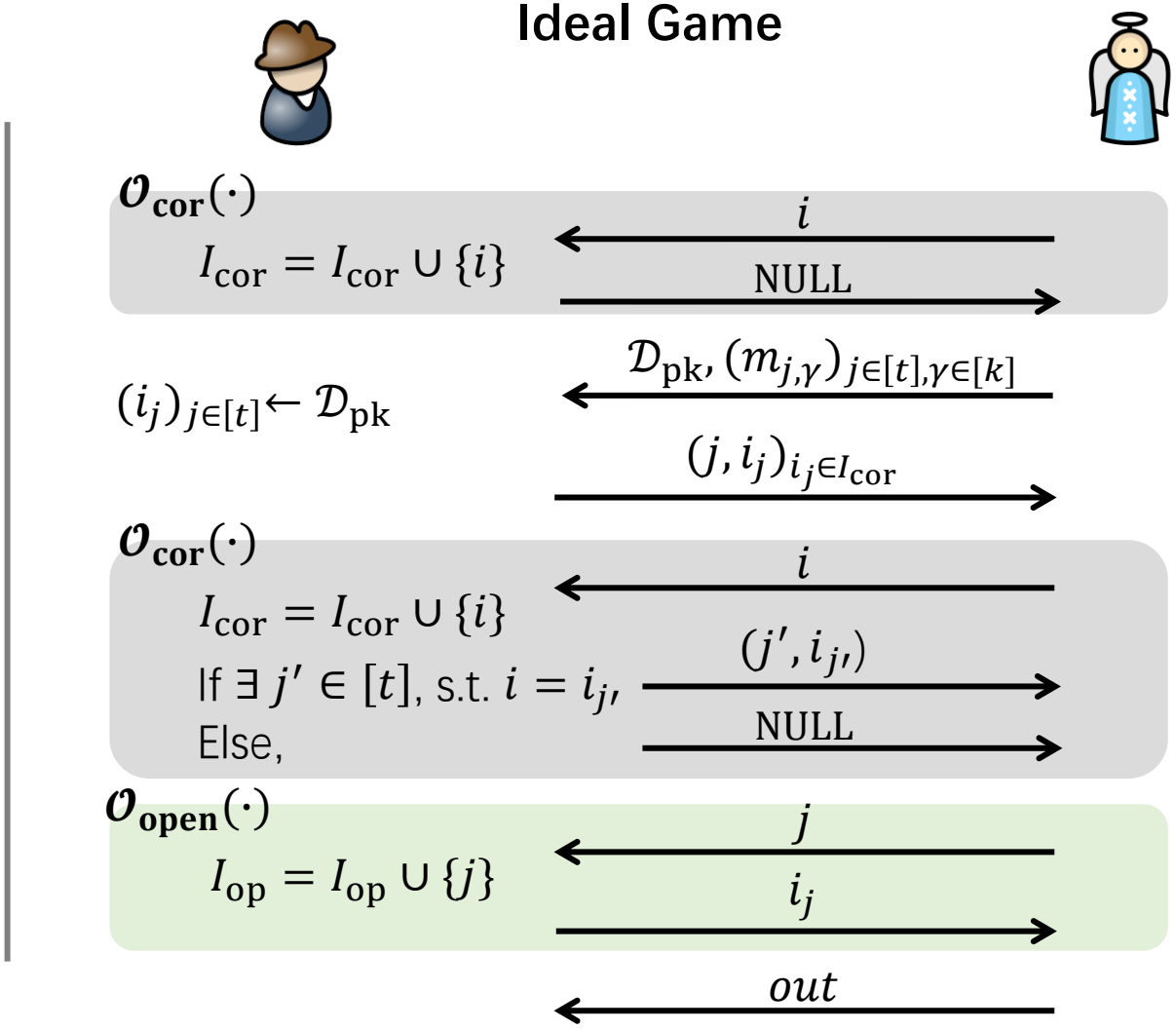
← sk_{i_j}

← out

Return $((i_j, (m_{j,\gamma})_{\gamma\in[k]})_{j\in[t]}, \mathcal{D}_{\mathrm{pk}}, I_{\mathrm{cor}}, I_{\mathrm{op}}, out)$

Definition: ANON-RSO$_k$&C-CPA security





Return $((i_j, (m_{j,\gamma})_{\gamma\in[k]})_{j\in[t]}, \mathcal{D}_{\mathrm{pk}}, I_{\mathrm{cor}}, I_{\mathrm{op}}, out)$

$\approx$

Return $((i_j, (m_{j,\gamma})_{\gamma\in[k]})_{j\in[t]}, \mathcal{D}_{\mathrm{pk}}, I_{\mathrm{cor}}, I_{\mathrm{op}}, out)$

Definition: SIM-RSOk&C-CPA security (confidentiality)

Real Game

$pk_1, \cdots, pk_n$

$\mathcal{O}_{\mathrm{cor}}(\cdot)$

$I_{\mathrm{cor}} = I_{\mathrm{cor}} \cup \{i\}$

i

sk_i

$\mathcal{D}_{\mathrm{m}}$

$(m_{i,\gamma})_{i\in[n],\gamma\in[k]} \leftarrow \mathcal{D}_{\mathrm{m}}$

$(c_{i,\gamma} \leftarrow \mathsf{Enc}(pk_i, m_{i,\gamma}))_{i\in[n],\gamma\in[k]}$

$(c_{i,\gamma})_{i\in[n],\gamma\in[k]}$

$\mathcal{O}_{\mathrm{cor}}(\cdot)$

$I_{\mathrm{cor}} = I_{\mathrm{cor}} \cup \{i\}$

i

sk_i

$\mathcal{O}_{\mathrm{open}}(\cdot)$

$I_{\mathrm{op}} = I_{\mathrm{op}} \cup \{i\}$

i

$sk_i, (m_{i,\gamma})_{\gamma\in[k]}$

out

Return $\left((m_{i,\gamma})_{i\in[n],\gamma\in[k]}, \mathcal{D}_{\mathrm{m}}, I_{\mathrm{cor}}, I_{\mathrm{op}}, out\right)$

$\approx$

Ideal Game

$\mathcal{O}_{\mathrm{cor}}(\cdot)$

$I_{\mathrm{cor}} = I_{\mathrm{cor}} \cup \{i\}$

i

NULL

$\mathcal{D}_{\mathrm{m}}$

$(m_{i,\gamma})_{i\in[n],\gamma\in[k]} \leftarrow \mathcal{D}_{\mathrm{m}}$

$(i, (m_{i,\gamma})_{\gamma\in[k]})_{i\in I_{\mathrm{cor}}}$

$\mathcal{O}_{\mathrm{cor}}(\cdot)$

$I_{\mathrm{cor}} = I_{\mathrm{cor}} \cup \{i\}$

i

$(m_{i,\gamma})_{\gamma\in[k]}$

$\mathcal{O}_{\mathrm{open}}(\cdot)$

$I_{\mathrm{op}} = I_{\mathrm{op}} \cup \{i\}$

i

$(m_{i,\gamma})_{\gamma\in[k]}$

out

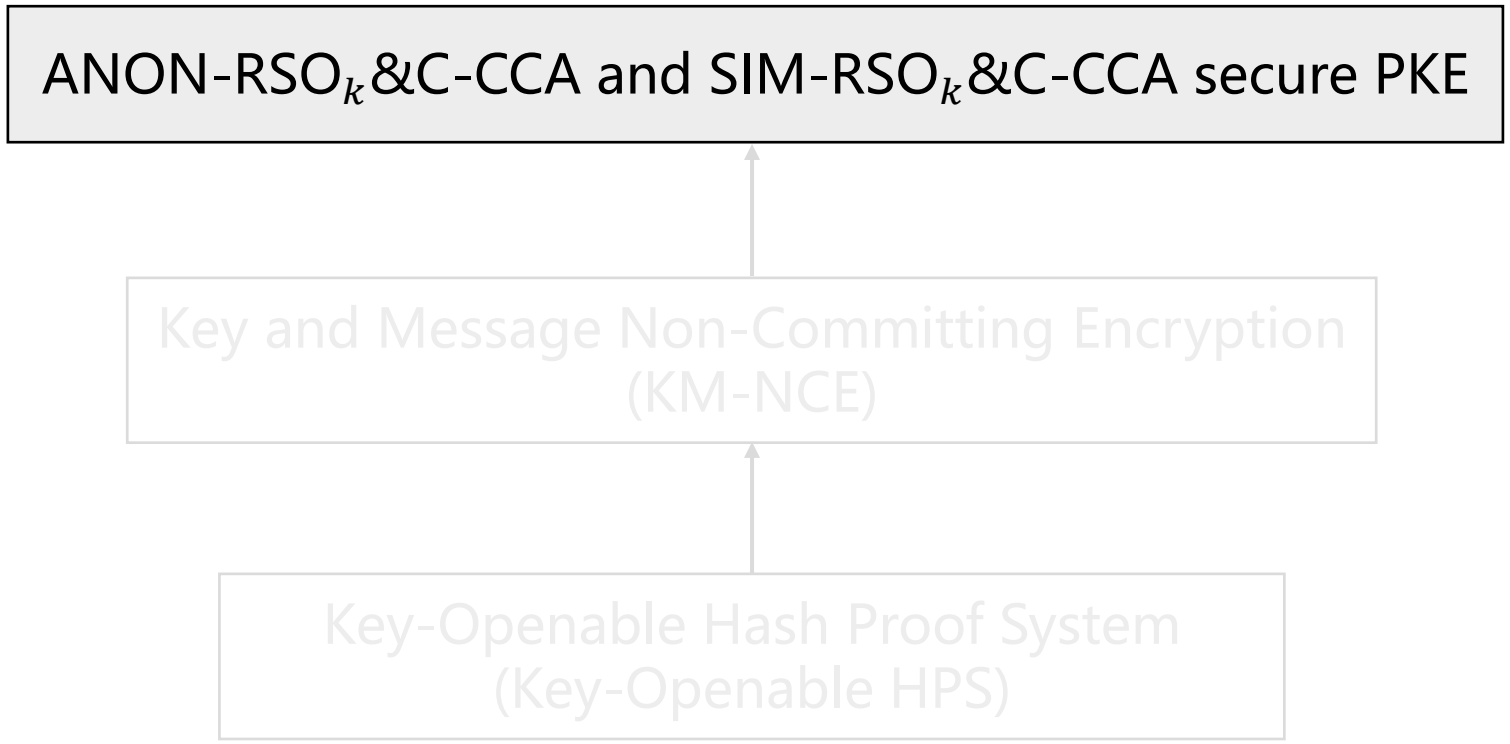
Return $\left((m_{i,\gamma})_{i\in[n],\gamma\in[k]}, \mathcal{D}_{\mathrm{m}}, I_{\mathrm{cor}}, I_{\mathrm{op}}, out\right)$

Relations among security notions

- **Anonymity:** ANON-RSOk&C-CPA ⇒ ANON-COR ([BGG+20, TCC])

- **Confidentiality:** SIM-RSOk&C-ATK ⇒ SIM-RSOk-ATK ([YLH+20, ASIACRYPT])

Construction – technical overview



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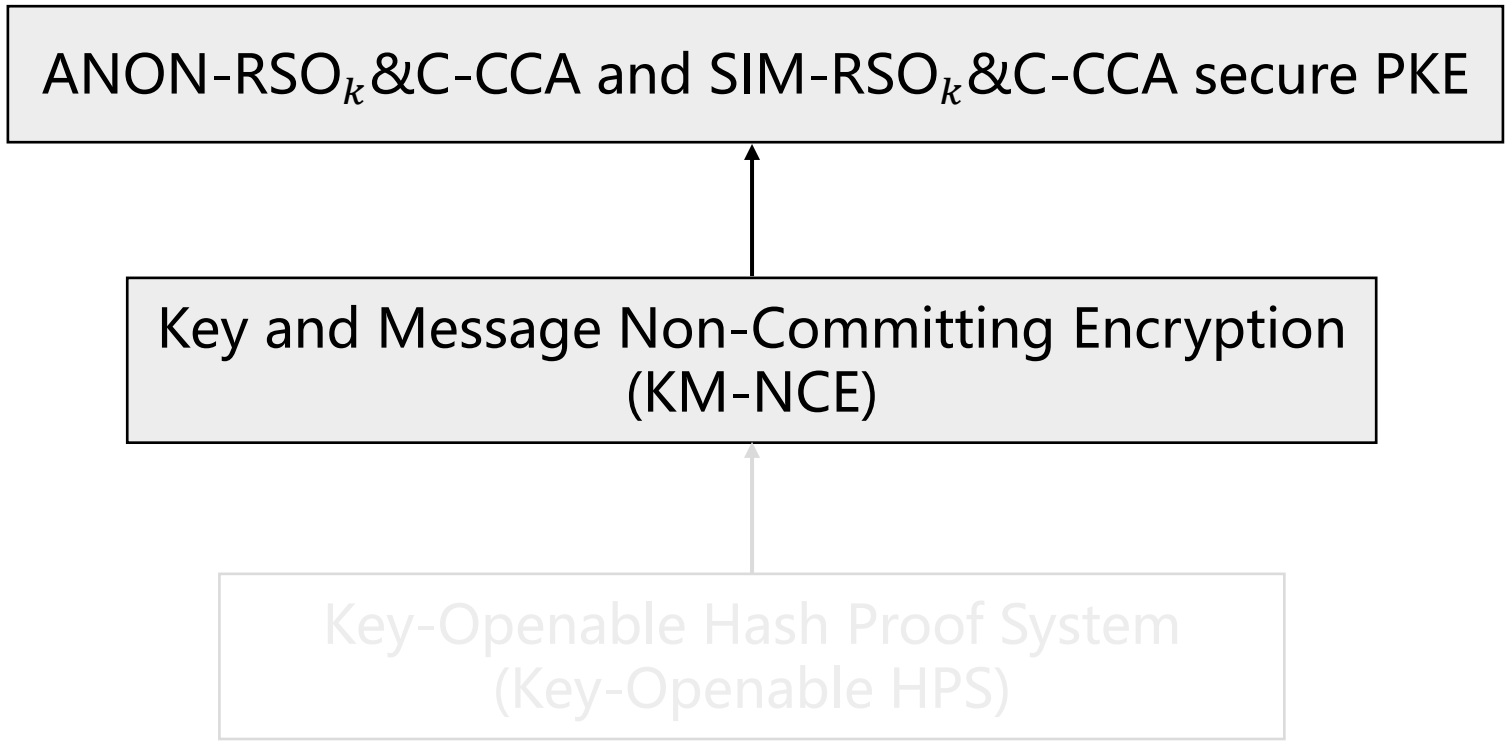

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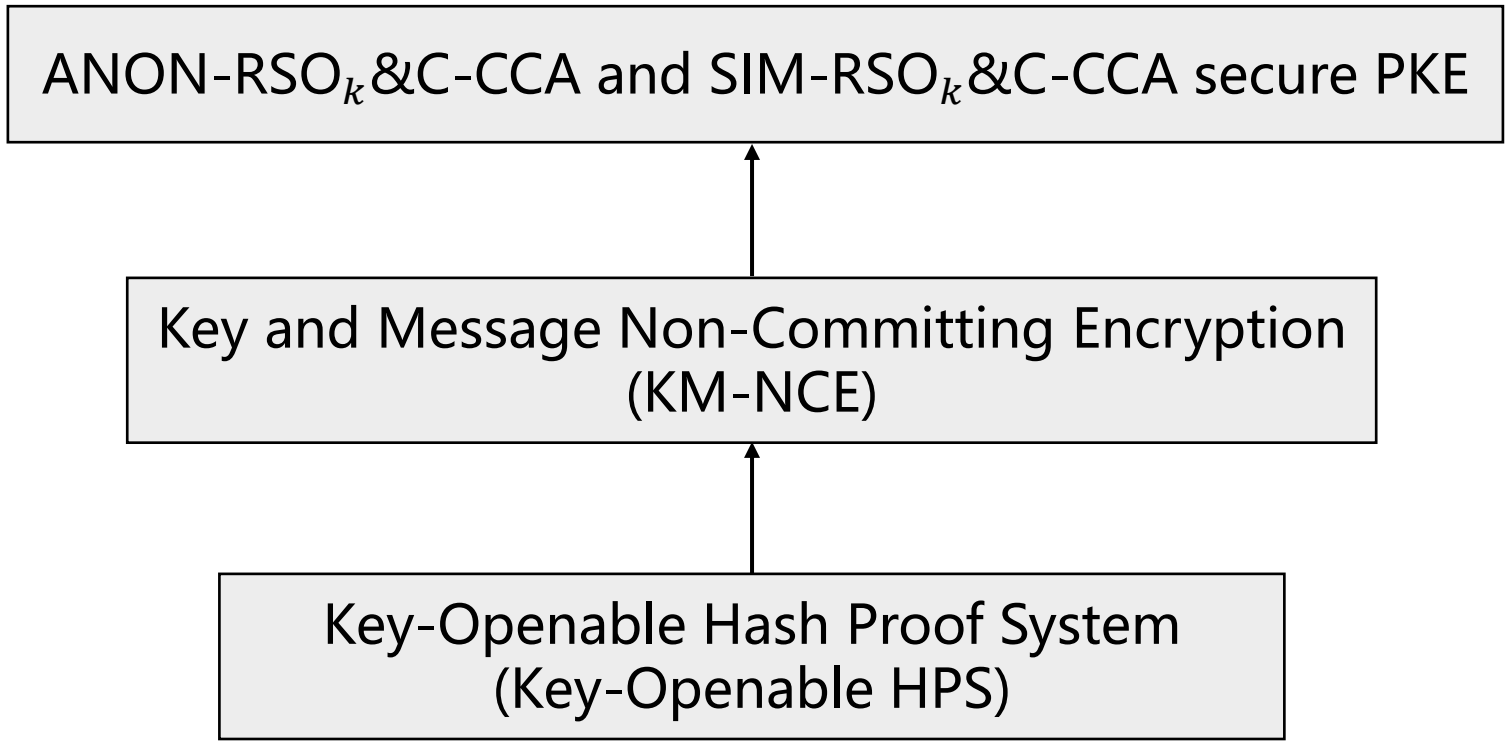
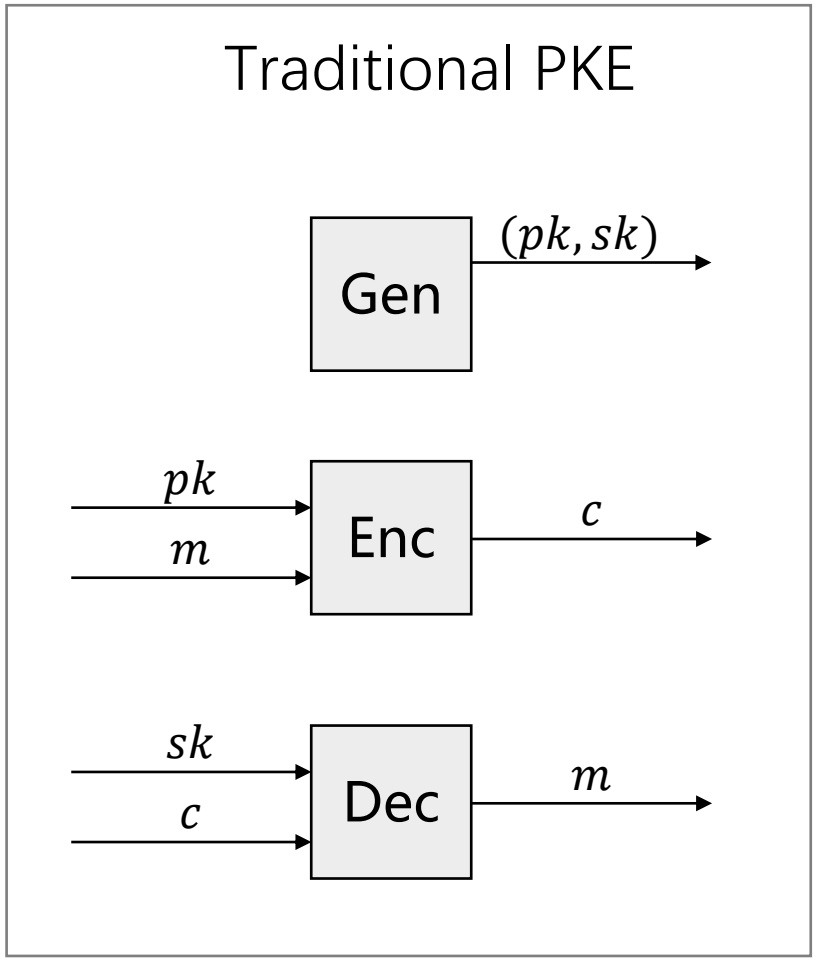
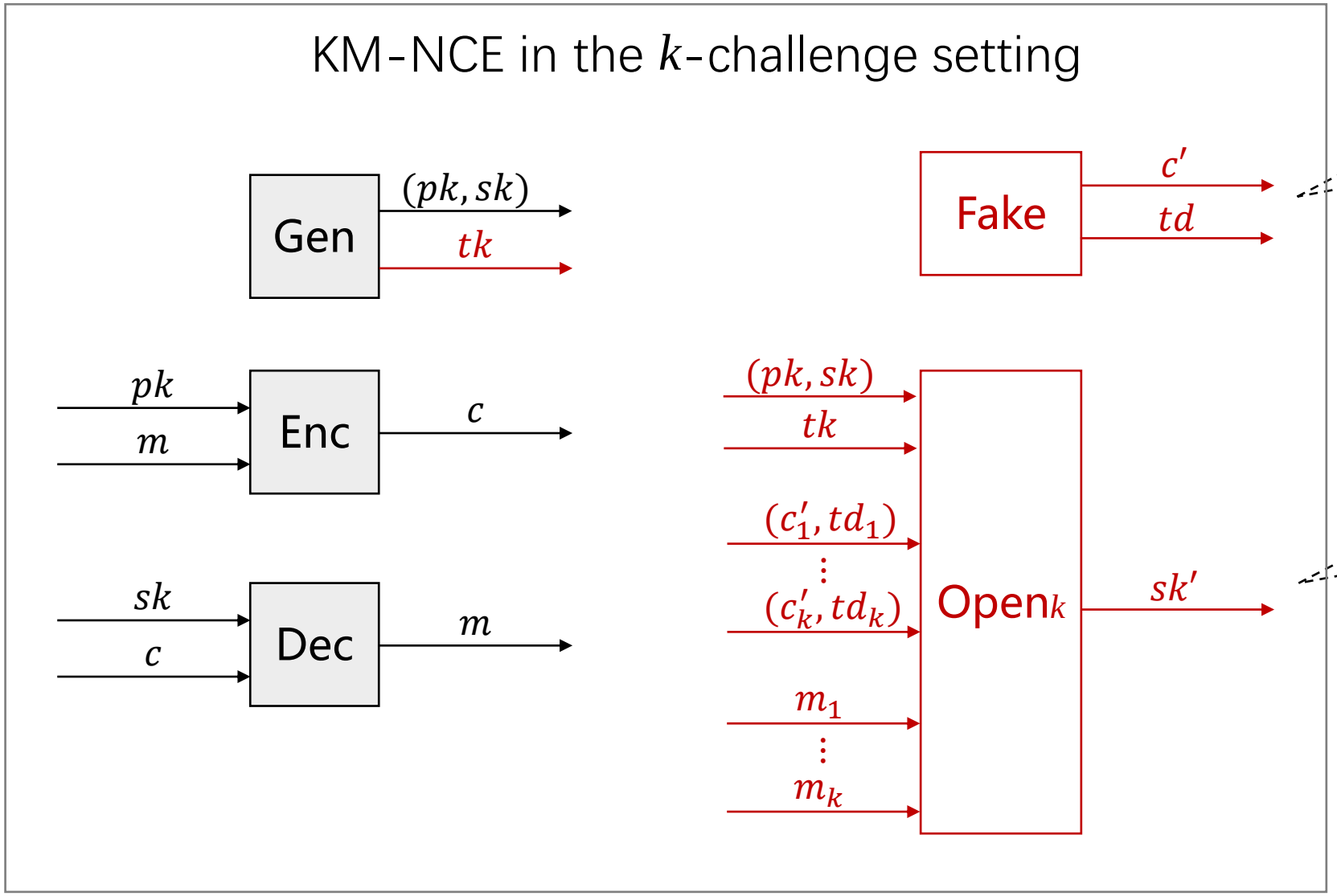


Key and Message Non-Committing Encryption



Key and Message Non-Committing Encryption



Generate fake ciphertexts without pk.

Open k fake ciphertexts to any k messages.

KM-NCE is an extension of Receiver NCE [CHK05, HPW15, HKM+18]

Security requirements of KM-NCE

KMNC$_k$-CPA security

For any $m_1, \dots, m_k$, for $(pk, sk, tk) \leftarrow \mathbf{Gen}(\lambda)$,

- k real ciphertexts:

  $(c_\gamma \leftarrow \mathbf{Enc}(pk, m_\gamma))_{\gamma \in [k]}$

- k fake ciphertexts and secret keys:

  $((c_\gamma^{\mathrm{fk}}, td_\gamma) \leftarrow \mathbf{Fake}(\lambda))_{\gamma \in [k]}$

  $sk^{\mathrm{op}} \leftarrow \mathbf{Open}_k(tk, pk, sk, (c_\gamma^{\mathrm{fk}}, td_\gamma, m_\gamma)_{\gamma \in [k]})$

$$(pk, sk, c_1, \dots, c_k) \approx (pk, sk^{\mathrm{op}}, c_1^{\mathrm{fk}}, \dots, c_k^{\mathrm{fk}})$$

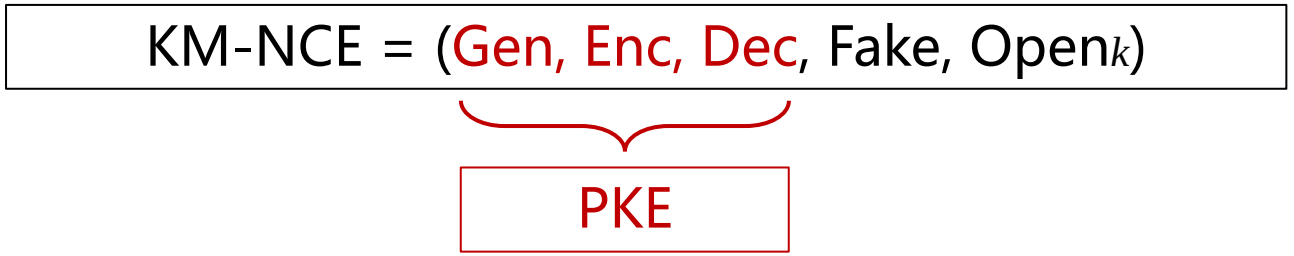
- KMNC$_k$-CCA security is similarly defined.

Robustness

For $(pk, sk, tk) \leftarrow \mathbf{Gen}(\lambda)$, $(c, td) \leftarrow \mathbf{Fake}(\lambda)$,

$\Pr[\mathbf{Dec}(sk, c) = \perp]$ is overwhelming.

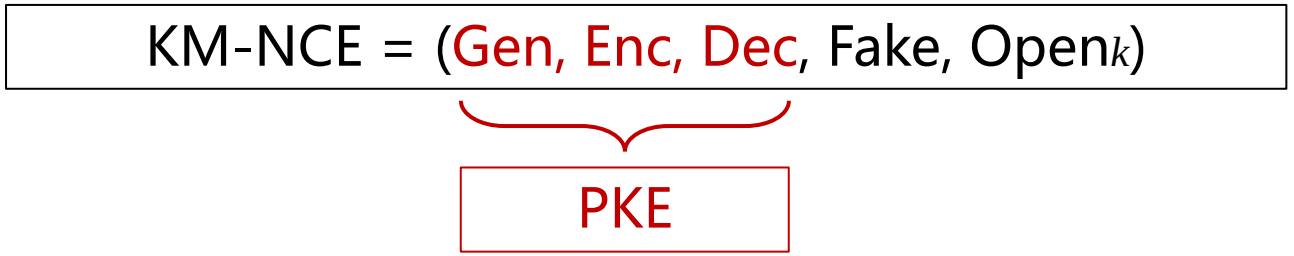
ANON / SIM -RSO$_k$&C secure PKE from KM-NCE



Theorem 1

- If **KM-NCE** is KMNC$_k$-CPA secure, then **PKE** is ANON-RSO$_k$&C-CPA secure and SIM-RSO$_k$&C-CPA secure .
- If **KM-NCE** is KMNC$_k$-CCA secure and robust, then **PKE** is ANON-RSO$_k$&C-CCA secure and SIM-RSO$_k$&C-CCA secure .

ANON / SIM -RSO$_k$&C secure PKE from KM-NCE



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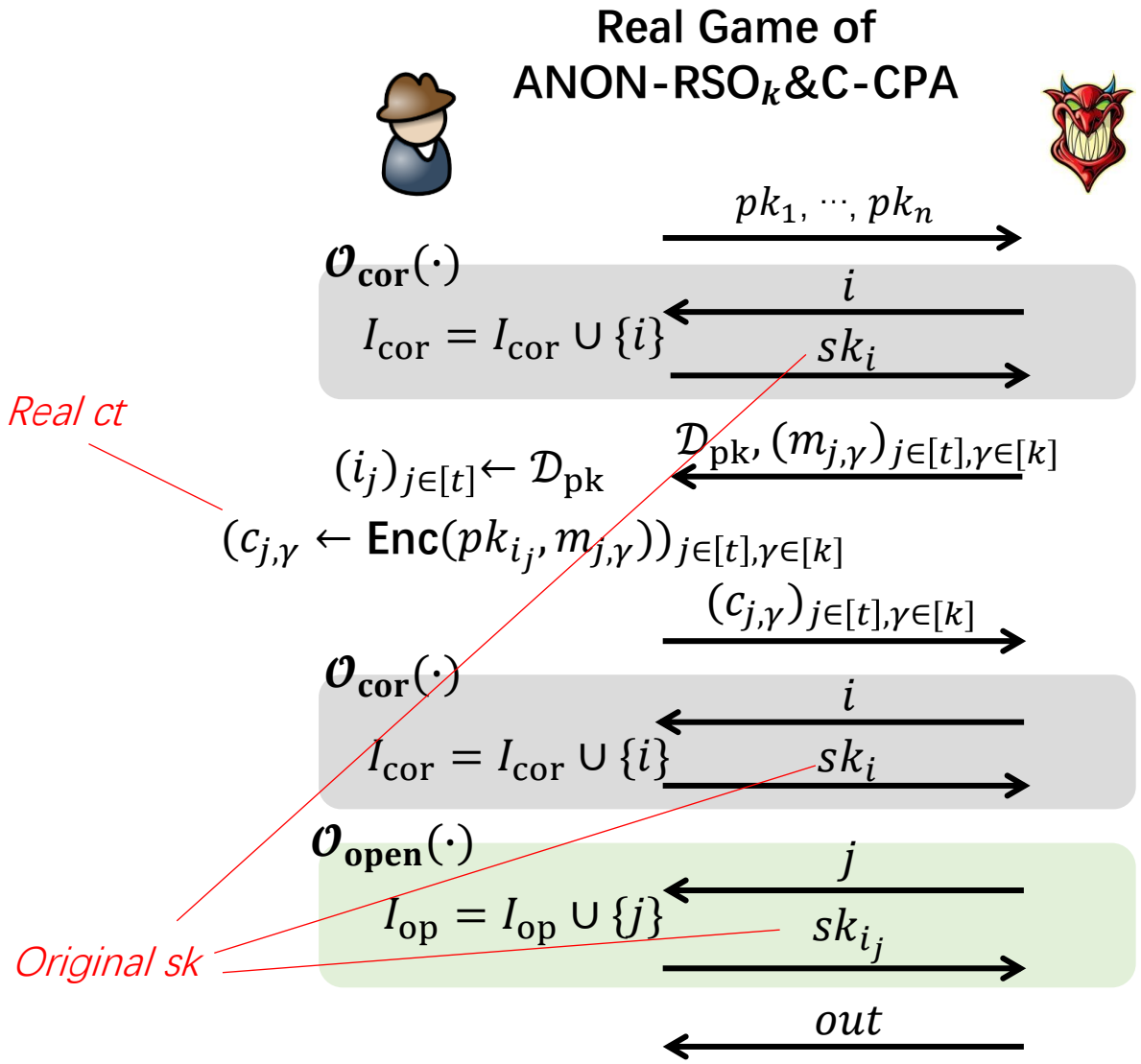
Proof: ANON-RSO$_k$&C-CPA secure PKE from KM-NCE



Proof: ANON-RSO$_k$&C-CPA secure PKE from KM-NCE

Ideal Game of ANON-RSO$_k$&C-CPA

$\mathcal{O}_{\mathbf{cor}}(\cdot)$
$I_{\mathrm{cor}} = I_{\mathrm{cor}} \cup \{i\}$

i ←
→ NULL

$(i_j)_{j\in[t]} \leftarrow \mathcal{D}_{\mathrm{pk}}$

$\mathcal{D}_{\mathrm{pk}}, (m_{j,\gamma})_{j\in[t],\gamma\in[k]}$ ←
$(j, i_j)_{i_j \in I_{\mathrm{cor}}}$ →

$\mathcal{O}_{\mathbf{cor}}(\cdot)$
$I_{\mathrm{cor}} = I_{\mathrm{cor}} \cup \{i\}$
If $\exists\, j' \in [t]$, s.t. $i = i_{j'}$,
Else,

i ←
$(j', i_{j'})$ →
→ NULL

$\mathcal{O}_{\mathbf{open}}(\cdot)$
$I_{\mathrm{op}} = I_{\mathrm{op}} \cup \{j\}$

j ←
i_j →
out ←

Return $((i_j, (m_{j,\gamma})_{\gamma\in[k]})_{j\in[t]}, \mathcal{D}_{\mathrm{pk}}, I_{\mathrm{cor}}, I_{\mathrm{op}}, out)$

$((pk_i, sk_i, tk_i) \leftarrow \mathrm{Gen}(\lambda))_{i\in[n]}$

For $j \in [t]$:
If $i_j \in I_{\mathrm{cor}}$: $(c_{j,\gamma} \leftarrow \mathbf{Enc}(pk_{i_j}, m_{j,\gamma}))_{\gamma\in[k]}$ — *Real ct*
If $i_j \notin I_{\mathrm{cor}}$: $(c_{j,\gamma} \leftarrow \mathbf{Fake}(\lambda))_{\gamma\in[k]}$ — *Fake ct*

If $(c_{j,\gamma})_{\gamma\in[k]}$ (or $(c_{j',\gamma})_{\gamma\in[k]}$) are real ct:
return sk_{i_j} (or $sk_{i_{j'}}$) as a response
If $(c_{j,\gamma})_{\gamma\in[k]}$ (or $(c_{j',\gamma})_{\gamma\in[k]}$) are fake ct:
return sk' generated with **Open**$_k$ as a response

Real Game of ANON-RSO$_k$&C-CPA

$pk_1, \cdots, pk_n$ →

$\mathcal{O}_{\mathbf{cor}}(\cdot)$
i ←
sk_i →

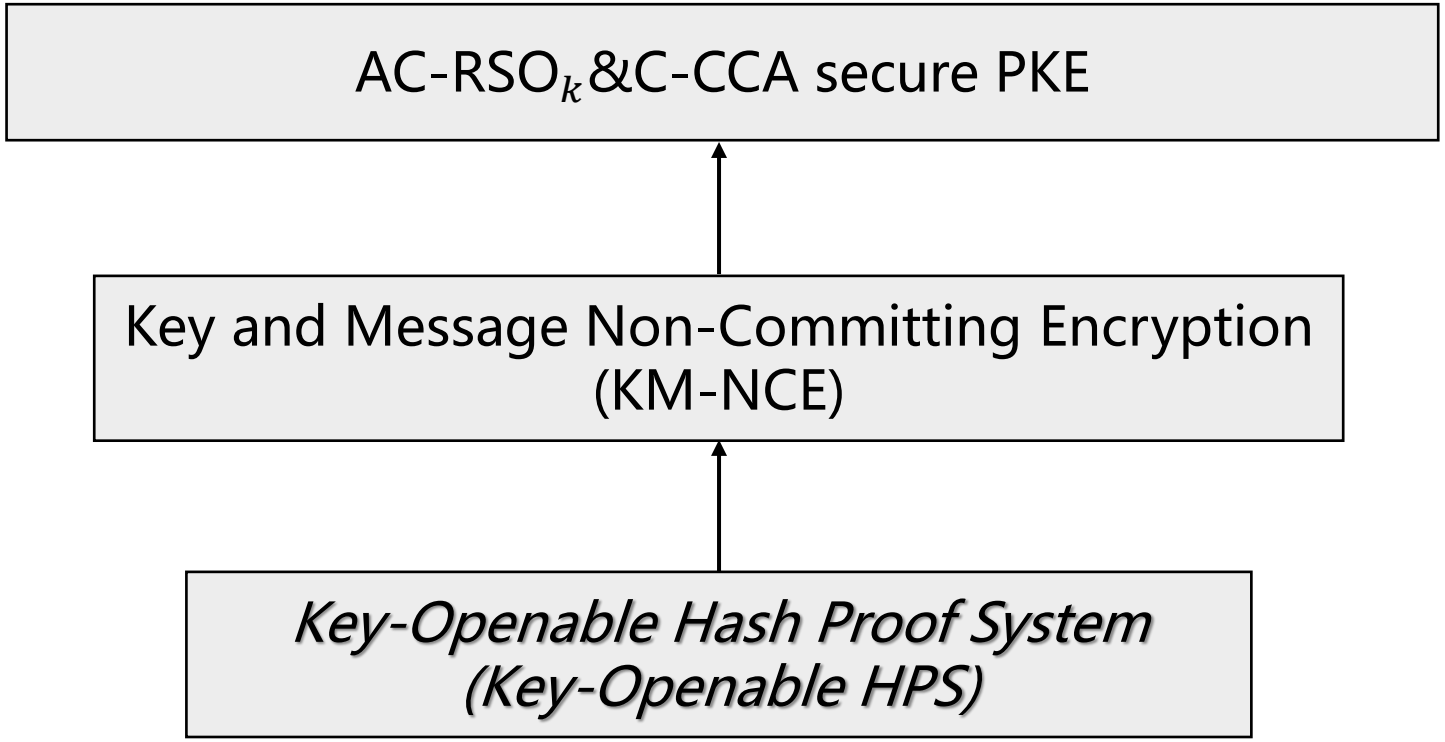
$\mathcal{D}_{\mathrm{pk}}, (m_{j,\gamma})_{j\in[t],\gamma\in[k]}$ ←

$(c_{j,\gamma})_{j\in[t],\gamma\in[k]}$ →

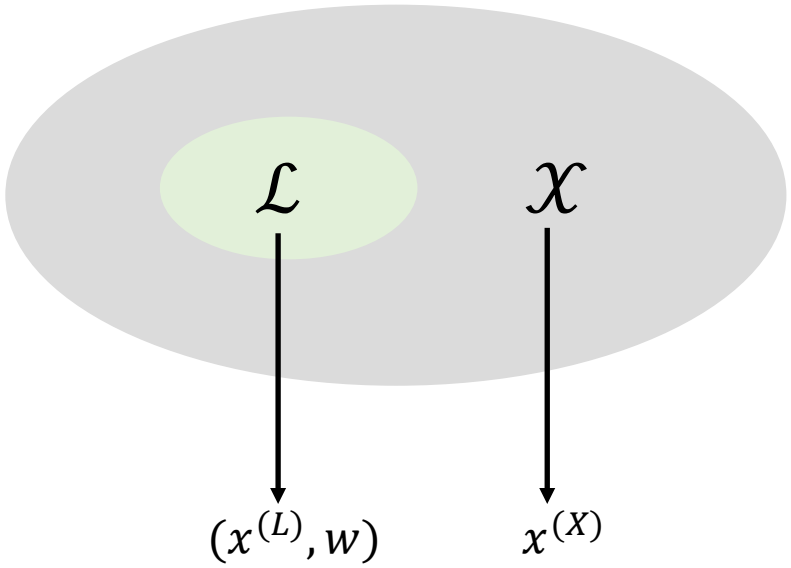
$\mathcal{O}_{\mathbf{cor}}(\cdot)$
i ←
sk_i →

$\mathcal{O}_{\mathbf{open}}(\cdot)$
j ←
sk_{i_j} →
out ←

Construction – technical overview



Key-Openable Hash Proof System



$Par(1^\lambda) \to (par, td)$, $KeyGen(par) \to (sk, pk)$

$Priv(sk, x) \to \pi$, $Pub(pk, x, w) \to \pi$

$HOpen_k(td, pk, sk, \left(x_\gamma, r_{x_\gamma}, \pi_\gamma, r_{\pi_\gamma}\right)_{\gamma \in [k]}) \to sk'/\perp$

Projectivity: For any $(x, w) \leftarrow \mathcal{L}$, $Priv\,(sk, x) = Pub\,(pk, x, w)$

Openability$_k$: $(par, td) \leftarrow Par$, $(sk_0, pk) \leftarrow KeyGen(par)$,

$(x_\gamma \leftarrow \mathcal{X}$ with uniform random $r_{x_\gamma})_{\gamma \in [k]}$, $(\pi_\gamma^{(0)} = Priv(sk_0, x_\gamma))_{\gamma \in [k]}$,

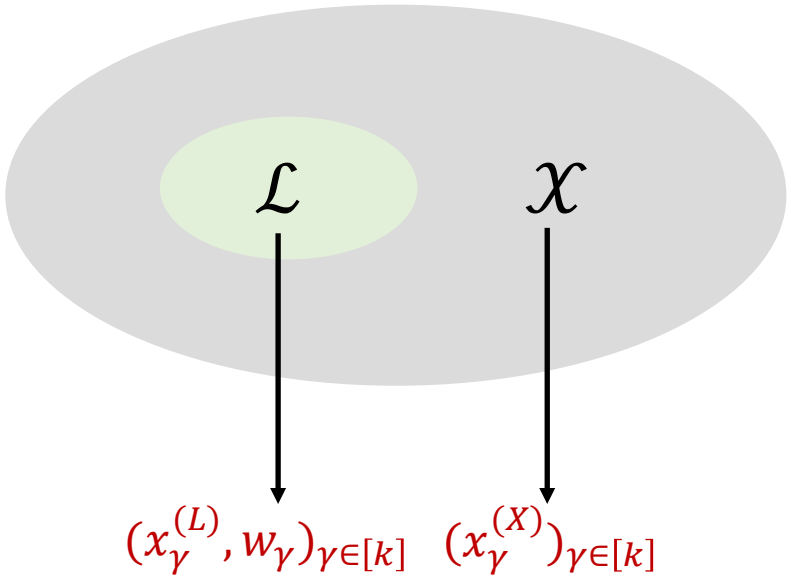
$(\pi_\gamma^{(1)} \leftarrow \Pi$ with uniform random $r_{\pi_\gamma^{(1)}})_{\gamma \in [k]}$,

$sk_1 \leftarrow HOpen_k(td, pk, sk, \left(x_\gamma, r_{x_\gamma}, \pi_\gamma^{(1)}, r_{\pi_\gamma^{(1)}}\right)_{\gamma \in [k]})$,

$(td, pk, sk_0, \left(x_\gamma, r_{x_\gamma}, \pi_\gamma^{(0)}\right)_{\gamma \in [k]}) \approx_s (td, pk, sk_1, \left(x_\gamma, r_{x_\gamma}, \pi_\gamma^{(1)}\right)_{\gamma \in [k]})$.

SMP: $x^{(L)} \approx_c x^{(X)}$

Key-Openable Hash Proof System



Multi-fold SMP:

$$(x_\gamma^{(L)})_{\gamma\in[k]} \approx_c (x_\gamma^{(X)})_{\gamma\in[k]}$$

Informally, guarantee that $HOpen_k$ can open uniformly sampled $(\pi_\gamma)_{\gamma\in[k]}$ to uniformly sampled $(x_\gamma)_{\gamma\in[k]}$

$$Par(1^\lambda) \to (par, td),\ KeyGen(par) \to (sk, pk)$$
$$Priv(sk, x) \to \pi,\ Pub(pk, x, w) \to \pi$$
$$HOpen_k(td, pk, sk, \left(x_\gamma, r_{x_\gamma}, \pi_\gamma, r_{\pi_\gamma}\right)_{\gamma\in[k]}) \to sk'/\perp$$

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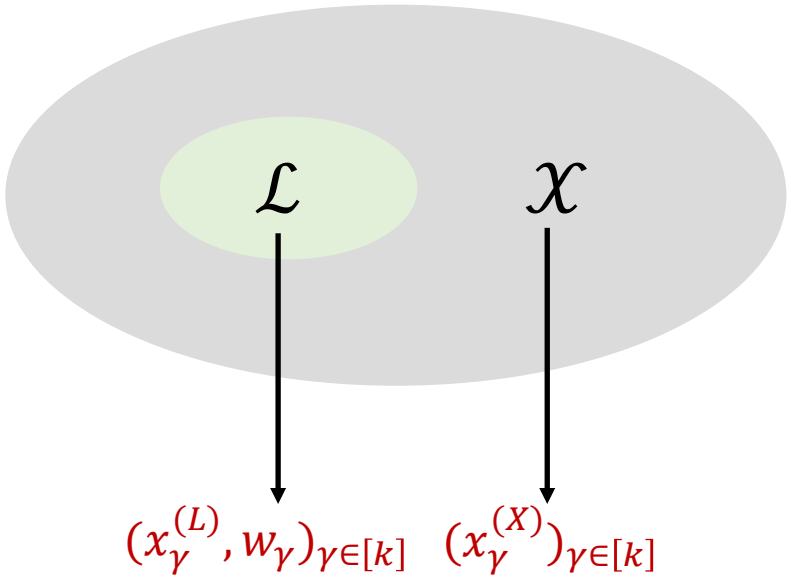
Key-Openable Hash Proof System



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Efficient randomness resampling on Π: there is a PPT $ReSmp_\Pi$, s.t., $\pi \leftarrow \Pi$ with uniform random r_π, $\pi' \leftarrow \Pi$, and $r_{\pi'} \leftarrow ReSmp_\Pi(\pi')$,

$$(\pi, r_\pi) \approx_s (\pi', r_{\pi'}).$$

Key-Openable Hash Proof System

MDDH-based Instantiation

(a generalization of the DDH-based HPS [CS02])

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$Priv(sk, x) \to \pi$, $Pub(pk, x, w) \to \pi$

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https://eprint.iacr.org/2022/1176

Construction of KM-NCE from Key-Openable HPS

HPS $=$ (HPS.Par, HPS.$KeyGen$, HPS.$Priv$, HPS.Pub, HPS.$HOpen_k$) is a key-openable hash proof system, whose hash value space supports efficient randomness resampling (w.r.t. HPS.$ReSmp_\Pi$).

KM-NCE = (Gen, Enc, Dec, Fake, Open$_k$)

Gen(1^λ):
$(par, td) \leftarrow$ HPS.$Par(1^\lambda)$
$(sk, pk) \leftarrow$ HPS.$KeyGen(par)$
$SK = sk$
$PK = (par, pk)$
$TK = td$

Enc(pk, m):
$x \leftarrow \mathcal{L}$ with witness w
$\pi =$ HPS.$Pub(pk, x, w) + m \in \Pi$
$C = (x, \pi)$

Dec$(sk, C = (x, \pi))$:
$m = \pi -$ HPS.$Priv(sk, x)$

Fake(1^λ):
$x \leftarrow \mathcal{X}$ with randomness r_x
$\pi \leftarrow \Pi$
$C = (x, \pi)$
$TD = r_x$

Open$_k(PK, SK, TK, (C_\gamma, TD_\gamma, m_\gamma)_{\gamma\in[k]})$:
Parse $TK = td$, $(C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]}$, $(TD_\gamma = r_{x_\gamma})_{\gamma\in[k]}$
For $\gamma \in [k]$:
$e_\gamma = \pi_\gamma - m_\gamma,\ r_{e_\gamma} \leftarrow$ HPS.$ReSmp_\Pi(e_\gamma)$
$sk' \leftarrow$ HPS.$HOpen_k(td, pk, sk, (x_\gamma, r_{x_\gamma}, e_\gamma, r_{e_\gamma})_{\gamma\in[k]})$
$SK' = sk'$

KMNC_k-CPA Security of the KM-NCE construction

KMNC_k-CPA security

For any $m_1, \ldots, m_k$, for $(pk, sk, tk) \leftarrow \mathbf{Gen}(\lambda)$,

- k real ciphertexts:

  $(c_\gamma \leftarrow \mathbf{Enc}(pk, m_\gamma))_{\gamma \in [k]}$

- k fake ciphertexts and secret keys:

  $((c_\gamma^{\mathrm{fk}}, td_\gamma) \leftarrow \mathbf{Fake}(\lambda))_{\gamma \in [k]}$

  $sk^{\mathrm{op}} \leftarrow \mathbf{Open}_k(tk, pk, sk, (c_\gamma^{\mathrm{fk}}, td_\gamma, m_\gamma)_{\gamma \in [k]})$

$$(pk, sk, c_1, \ldots, c_k) \approx (pk, sk^{\mathrm{op}}, c_1^{\mathrm{fk}}, \ldots, c_k^{\mathrm{fk}})$$

KMNC_k-CPA Security of the KM-NCE construction

Real: $(PK, SK = sk, (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$

$\equiv$

G_0 : $(PK, SK = sk, (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$: $x_\gamma \leftarrow \mathcal{L}$ with witness w_γ; $\pi_\gamma = \mathrm{HPS}.Pub(pk, x_\gamma, w_\gamma) + m_\gamma$

Projectivity

G_1 : $(PK, SK = sk, (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$: $x_\gamma \leftarrow \mathcal{L}$ with witness w_γ; $\pi_\gamma = \mathrm{HPS}.Priv(sk, x_\gamma) + m$

Multi-fold SMP

G_2 : $(PK, SK = sk, (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$: $x_\gamma \leftarrow \mathcal{X}$ with rendomness r_{x_γ}; $\pi_\gamma = \mathrm{HPS}.Priv(sk, x_\gamma) + m$

Openability$_k$

G_3 : $(PK, SK = sk', (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$: $x_\gamma \leftarrow \mathcal{X}$ with rendomness r_{x_γ}; $\pi_\gamma \leftarrow \Pi$;

$e_\gamma = \pi_\gamma - m_\gamma$, $r_{e_\gamma} \leftarrow \mathrm{HPS}.ReSmp_\Pi(e_\gamma)$,

$sk' \leftarrow \mathrm{HPS}.HOpen_k(td, pk, sk, (x_\gamma, r_{x_\gamma}, e_\gamma, r_{e_\gamma})_{\gamma\in[k]})$

Fake: $(PK, SK = sk', (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$

KMNC$_k$-CPA Security of the KM-NCE construction

Real: $(PK, SK = sk, (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$

$\equiv$

G_0 : $(PK, SK = sk, (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$: $x_\gamma \leftarrow \mathcal{L}$ with witness w_γ; $\pi_\gamma = \text{HPS}.Pub(pk, x_\gamma, w_\gamma) + m_\gamma$

Projectivity

G_1 : $(PK, SK = sk, (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$: $x_\gamma \leftarrow \mathcal{L}$ with witness w_γ; $\pi_\gamma = \text{HPS}.Priv(sk, x_\gamma) + m$

Multi-fold SMP

G_2 : $(PK, SK = sk, (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$: $x_\gamma \leftarrow \mathcal{X}$ with rendomness r_{x_γ}; $\pi_\gamma = \text{HPS}.Priv(sk, x_\gamma) + m$

Openability$_k$

G_3 : $(PK, SK = sk', (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$: $x_\gamma \leftarrow \mathcal{X}$ with rendomness r_{x_γ}; $\pi_\gamma \leftarrow \Pi$;

$e_\gamma = \pi_\gamma - m_\gamma$, $r_{e_\gamma} \leftarrow \text{HPS}.ReSmp_\Pi(e_\gamma)$,

$sk' \leftarrow \text{HPS}.HOpen_k(td, pk, sk, (x_\gamma, r_{x_\gamma}, e_\gamma, r_{e_\gamma})_{\gamma\in[k]})$

$\equiv$

Fake: $(PK, SK = sk', (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$

Open$_k$

KMNC_k-CPA Security of the KM-NCE construction

Real: $(PK, SK = sk, (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$

II

G_0 : $(PK, SK = sk, (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$: $x_\gamma \leftarrow \mathcal{L}$ with witness w_γ; $\pi_\gamma = \mathrm{HPS}.Pub(pk, x_\gamma, w_\gamma) + m_\gamma$

Projectivity

G_1 : $(PK, SK = sk, (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$: $x_\gamma \leftarrow \mathcal{L}$ with witness w_γ; $\pi_\gamma = \mathrm{HPS}.Priv(sk, x_\gamma) + m$

Multi-fold SMP

G_2 : $(PK, SK = sk, (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$: $x_\gamma \leftarrow \mathcal{X}$ with rendomness r_{x_γ}; $\pi_\gamma = \mathrm{HPS}.Priv(sk, x_\gamma) + m$

Openability$_k$

G_3 : $(PK, SK = sk', (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$: $x_\gamma \leftarrow \mathcal{X}$ with rendomness r_{x_γ}; $\pi_\gamma \leftarrow \Pi$;

$e_\gamma = \pi_\gamma - m_\gamma$, $r_{e_\gamma} \leftarrow \mathrm{HPS}.ReSmp_\Pi(e_\gamma)$,

$sk' \leftarrow \mathrm{HPS}.HOpen_k(td, pk, sk, (x_\gamma, r_{x_\gamma}, e_\gamma, r_{e_\gamma})_{\gamma\in[k]})$

II

Fake: $(PK, SK = sk', (C_\gamma = (x_\gamma, \pi_\gamma))_{\gamma\in[k]})$

Open$_k$

For the CCA secure KM-NCE construction, please refer to https://eprint.iacr.org/2022/1176

Summary

- We formalize the notion of ANON-RSO$_k$&C security for PKE
  - ✓ANON-RSO$_k$&C-CPA ⇒ ANON-COR ([BGG+20, TCC])

- We formalize the notion of SIM-RSO$_k$&C security for PKE
  - ✓SIM-RSO$_k$&C-ATK ⇒ SIM-RSO$_k$-ATK ([YLH+20, ASIACRYPT])

- We show a framework of PKE achieving both ANON-RSO$_k$&C-CCA and SIM-RSO$_k$&C-CCA security
  - ✓The obtained MDDH-based scheme
    - ✓ has compact ciphertexts (i.e., ciphertext overhead is the size of a constant number of group elements);
    - ✓ has tight security reduction;
    - ✓ is the first PKE scheme achieving ANON-COR security ([BGG+20, TCC]).

https://eprint.iacr.org/2022/1176

References

[BGG+20] Fabrice Benhamouda, Craig Gentry, Sergey Gorbunov, Shai Halevi, Hugo Krawczyk, Chengyu Lin, Tal Rabin, and Leonid Reyzin. Can a public blockchain keep a secret? In TCC 2020, pages 260–290. Springer, 2020.

[CHK05] Ran Canetti, Shai Halevi, and Jonathan Katz. Adaptively-secure, noninteractive public-key encryption. In TCC 2005, pages 150–168. Springer, 2005.

[CS02] Ronald Cramer and Victor Shoup. Universal hash proofs and a paradigm for adaptive chosen ciphertext secure public-key encryption. In EUROCRYPT 2002, pages 45–64, 2002.

[HKM+18] Keisuke Hara, Fuyuki Kitagawa, Takahiro Matsuda, Goichiro Hanaoka, and Keisuke Tanaka. Simulation-based receiver selective opening CCA secure PKE from standard computational assumptions. In Security and Cryptography for Networks 2018, pages 140–159. Springer, 2018

[HPW15] Carmit Hazay, Arpita Patra, and Bogdan Warinschi. Selective opening security for receivers. In ASIACRYPT 2015, pages 443–469. Springer, 2015

[YLH+20] Rupeng Yang, Junzuo Lai, Zhengan Huang, Man Ho Au, Qiuliang Xu, and Willy Susilo. Possibility and impossibility results for receiver selective opening secure PKE in the multi-challenge setting. In ASIACRYPT 2020, pages 191–220. Springer, 2020.

Thanks for your Attention!