Unmasking TRaccoon:
A Lattice-Based Threshold Signature with An Efficient Identifiable Abort Protocol

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This presentation is based on results obtained from a project, JPNP24003, commissioned by the New Energy and Industrial Technology Development Organization (NEDO)

Our Identifiable Abort Protocol

Main Contribution: TRaccoon with Identifiable Abort Protocol

- Our interactive IA protocol is a simple add-on to TRaccoon
- Communication cost in IA protocol is $60 + 6.4 \cdot T$ KB per a signer

Side Contributions:

- The first game-based definition of TS with an *interactive* IA protocol
- The first formal security analysis of a variant of LaBRADOR with ZK

Background

T-out-of-N Threshold Signature

Verification key vk

$\Updownarrow$

Signing key sk

Key Generation

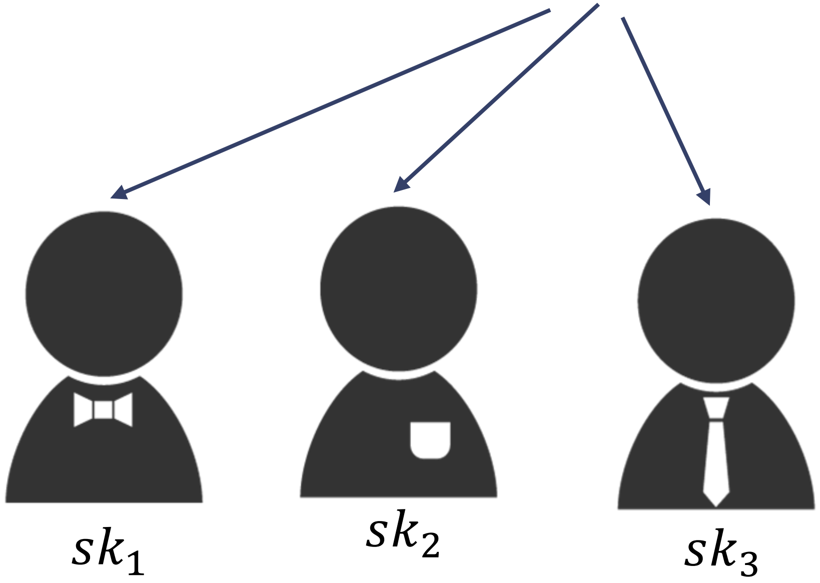
※2-out-of-3

T-out-of-N Threshold Signature

Verification key vk

⇕

Signing key $\underline{sk}$



※2-out-of-3

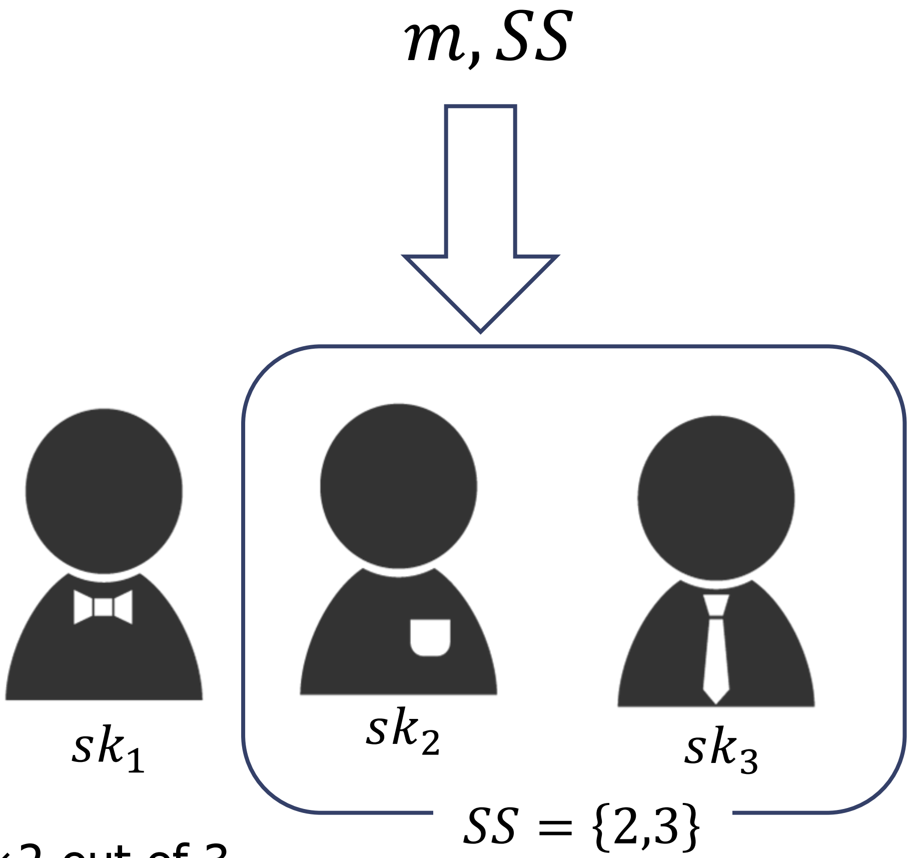
Key Generation

- T or more key shares reconstruct sk
- No signer knows sk
- Less than T key shares leak no information about sk

※We assume that a trusted party executes distributed key generation as well as [BCK+22,dPKM+24] etc.

T-out-of-N Threshold Signature

Signing Protocol



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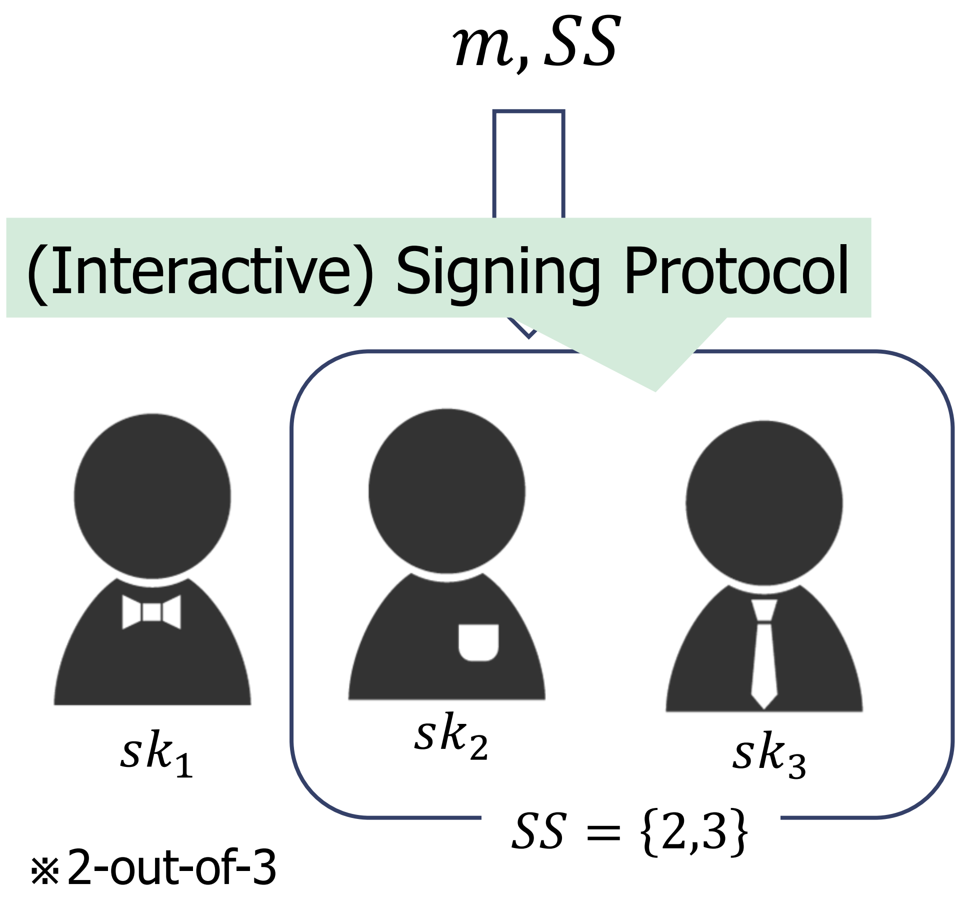

General Procedure:

1. One decides message m and signer set SS
2. Users in SS execute signing protocol

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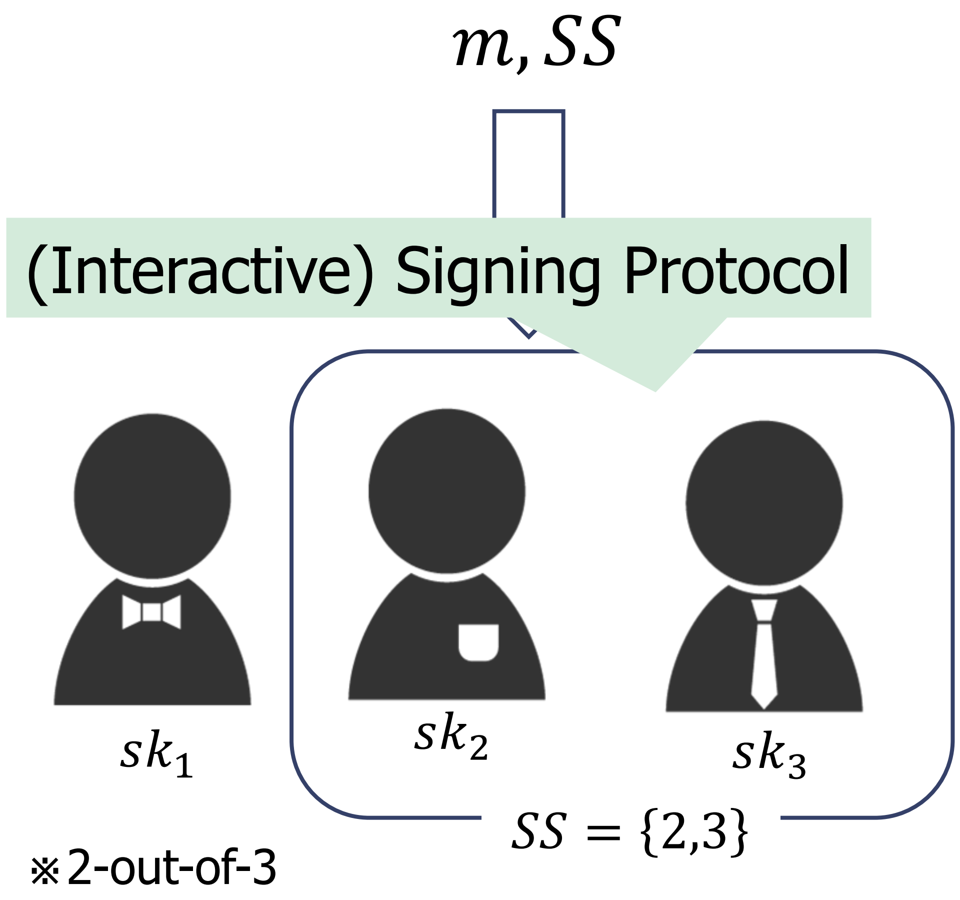

General Procedure:

1. One decides message m and signer set SS
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⇒ Signature σ

PQ Threshold Signature Schemes

Early Schemes: [BKP13], [BGG+18], [ASY22], [GKS23]
$\Rightarrow$The use of heavy tools, e.g., FHE and HTDC

Recent Schemes: [dPKM+24], [EKT24], [KRT24], [CATZ24], [BKL+25], etc
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<u>TRaccoon [dPKM+24]:</u>

- Three-round signing protocol
- Efficient sig size compared with early schemes

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One drawback: No Availability

Malicious signer can arbitrarily cause the signing protocol to fail

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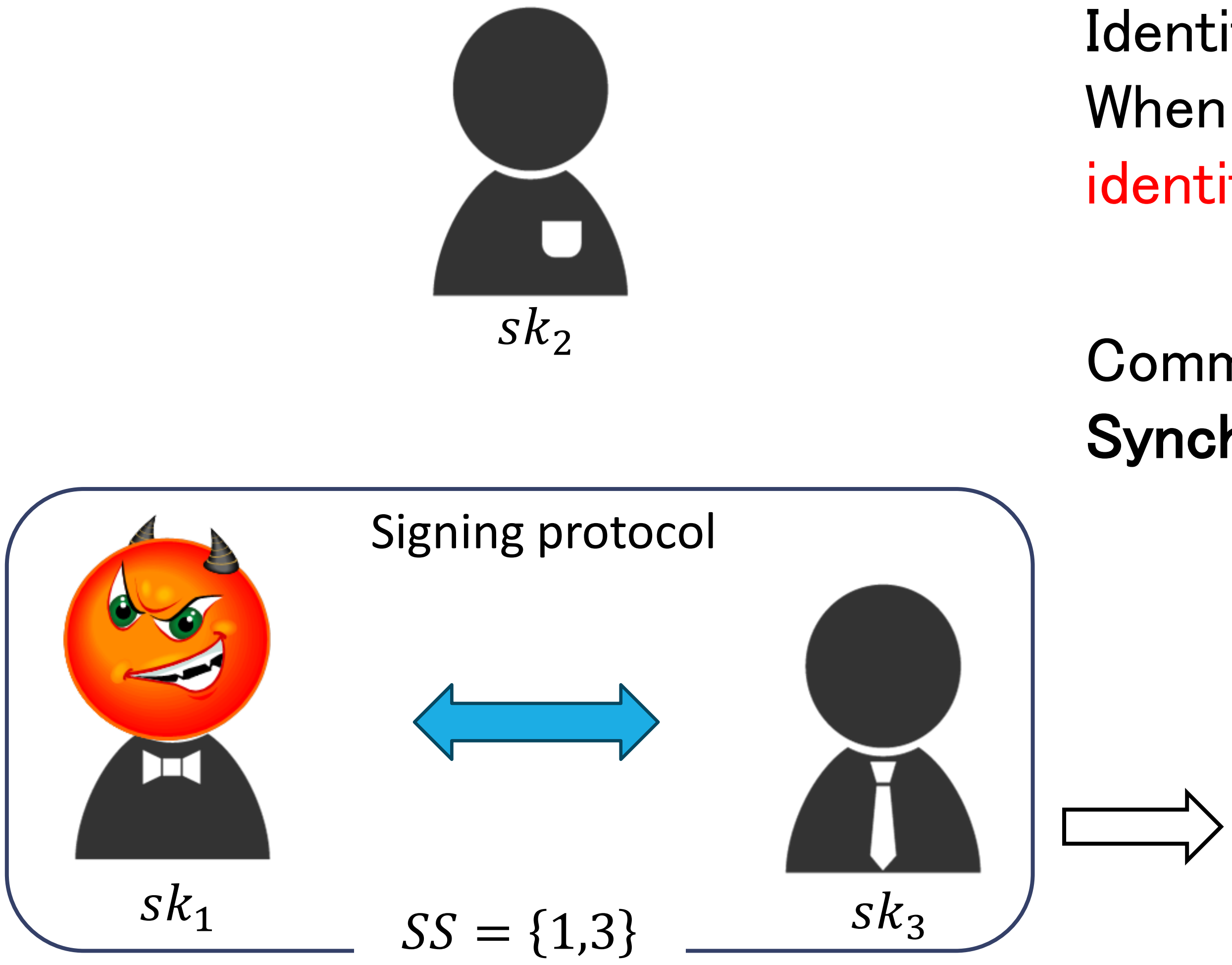
Availability for TS: Identifiable Abort



Identifiable Abort:
When the signing protocol fails, honest signers identify misbehaving signers.

Communication Channel:
Synchronous authenticated Broadcast

Valid σ
or
Signer 1 is misbehavior

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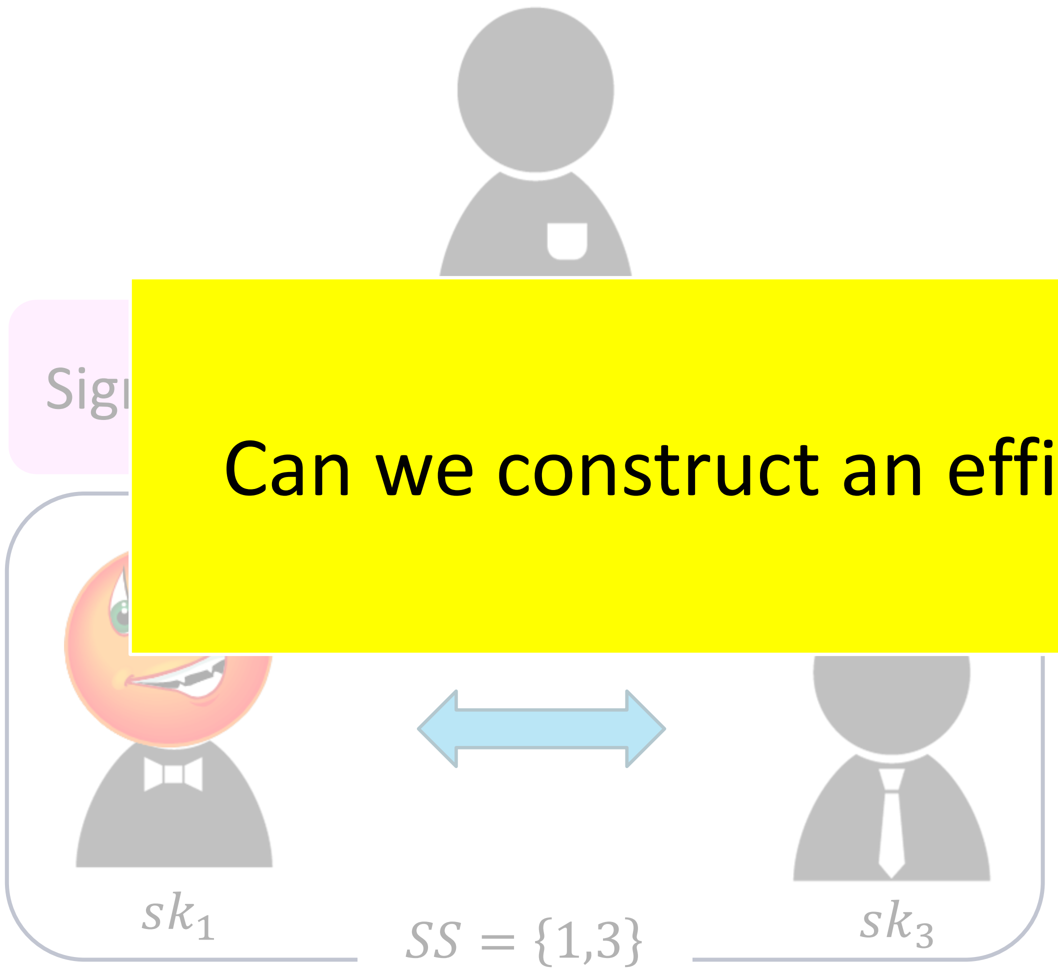


Can we construct an efficient IA protocol for TRaccoon?

Valid σ
or
Signer 1 is misbehavior

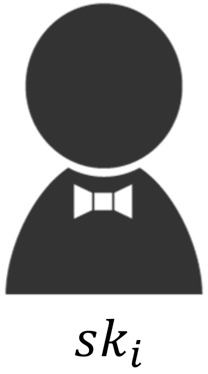
TRaccoon

Threshold Raccoon [dPKM+24]

vk: $\boldsymbol{A} \in \mathcal{R}_q^{k\times\ell}, \boldsymbol{t} = \boldsymbol{A}\cdot\boldsymbol{s} + \boldsymbol{e}$ where short vectors $(\boldsymbol{s}, \boldsymbol{e}) \in \mathcal{R}_q^{\ell} \times \mathcal{R}_q^{k}$

sk_i: $\boldsymbol{s}_i$ is a secret share of $\boldsymbol{s}$, $\left(seed_{i,j}, seed_{j,i}\right)_{j\in[N]}$ are pair-wise seeds.

Lattice variant of Sparkle[CKM23]



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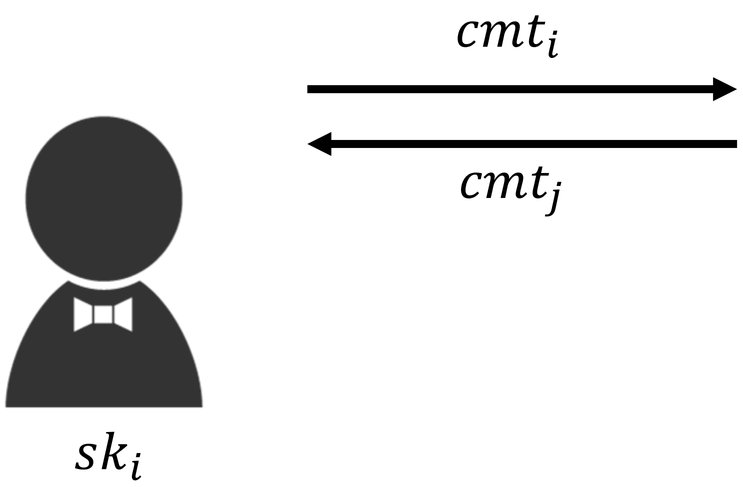

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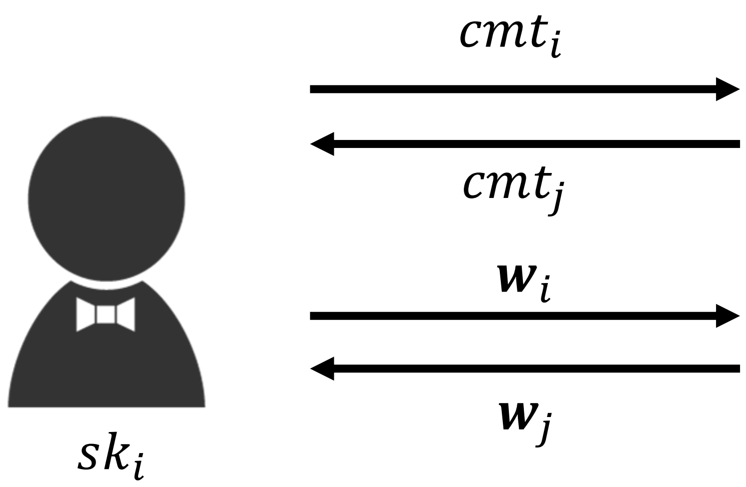

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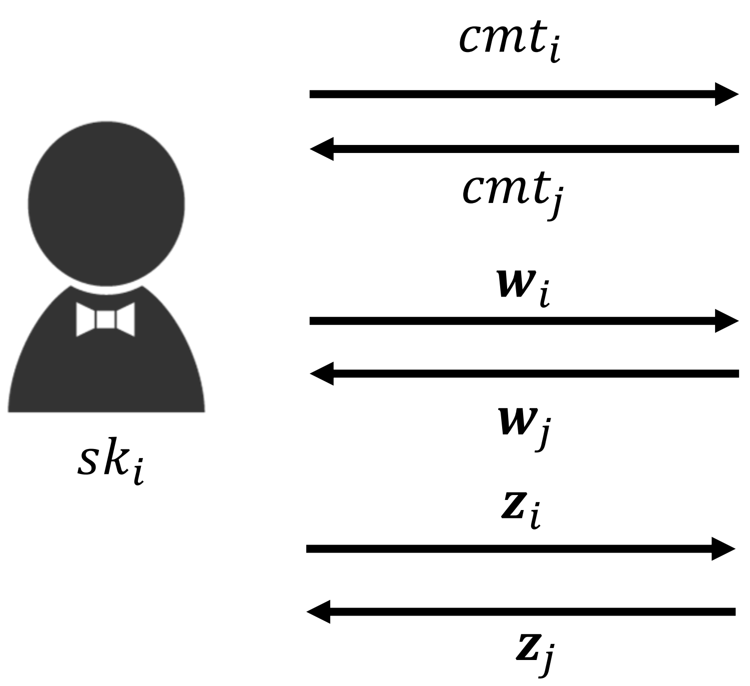
Round 3:

1. Check $cmt_j = H(\boldsymbol{w}_j)$
2. $\boldsymbol{w} \leftarrow \sum_j \boldsymbol{w}_j$
3. $c \leftarrow H_c(vk, m, \boldsymbol{w})$
4. Broadcast $\boldsymbol{z}_i \leftarrow c \cdot L_{SS,i} \cdot \boldsymbol{s}_i + \boldsymbol{r}_i + \Delta_i$



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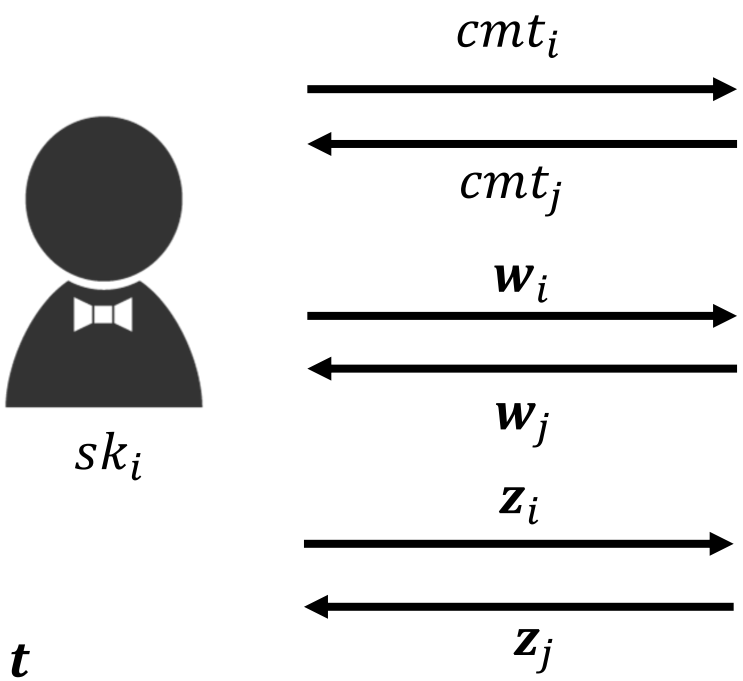

Resulting signature: $(c, \boldsymbol{z}, \boldsymbol{h})$ where $\boldsymbol{z} = \sum_i \boldsymbol{z}_i$, $\boldsymbol{h} = \boldsymbol{w} - \boldsymbol{A}\cdot\boldsymbol{z} + c\cdot\boldsymbol{t}$
Verification: $c = H_c(vk, m, \boldsymbol{A}\cdot\boldsymbol{z} - c\cdot\boldsymbol{t} + \boldsymbol{h})$

Threshold Raccoon [dPKM+24]

vk:
sk_i:

Rou

Rou

Rou

Important difference from Sparkle:

Masking Term: $\Delta_i = \sum_j (\boldsymbol{m}_{i,j} - \boldsymbol{m}_{j,i})$ such that $\sum_i \Delta_i = 0$

where $\boldsymbol{m}_{i,j} = H_{msk}(seed_{i,j}, ctnt_z), ctnt_z = SS||m||(cmt_i, w_i)_{i \in SS}$.

This is a crucial component to prevent lattice-specific attacks.

2. $\boldsymbol{w} \leftarrow \sum_j \boldsymbol{w}_j$

3. $c \leftarrow H_c(vk, m, \boldsymbol{w})$

4. Broadcast $\boldsymbol{z}_i \leftarrow c \cdot L_{SS,i} \cdot \boldsymbol{s}_i + \boldsymbol{r}_i + \Delta_i$

sk_1 $\boldsymbol{w}_j$ $\boldsymbol{z}_i$ $\boldsymbol{z}_j$

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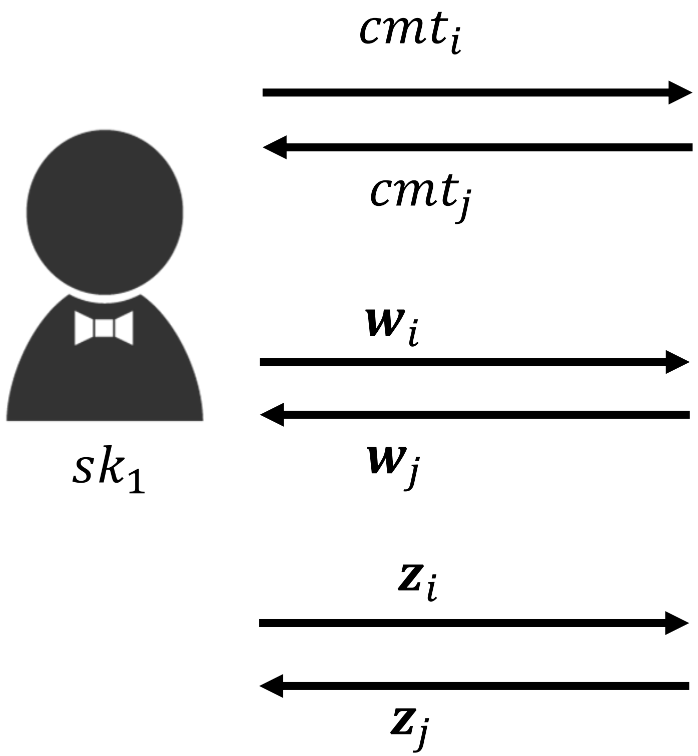
Our Approach

Straightforward Approach

All signers prove that they honestly executed the signing protocol for each round.



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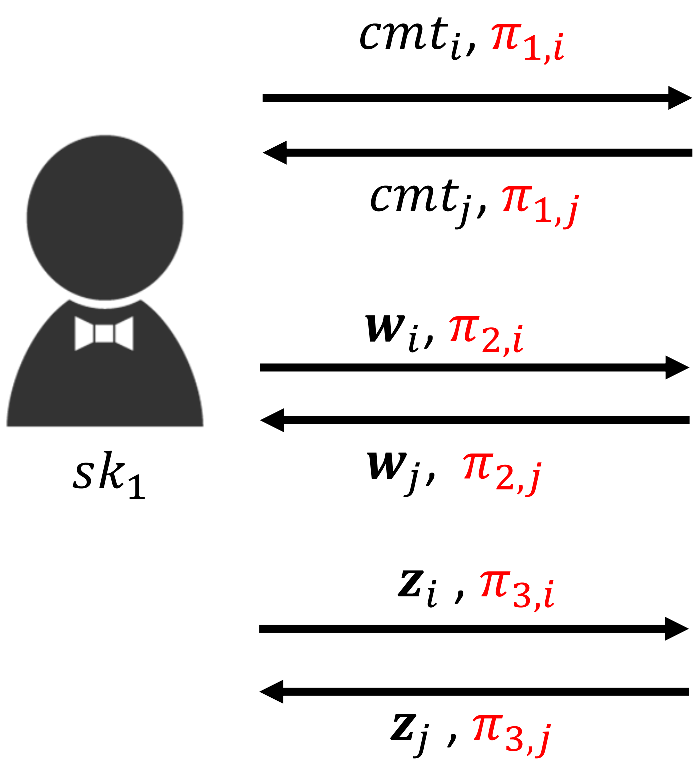
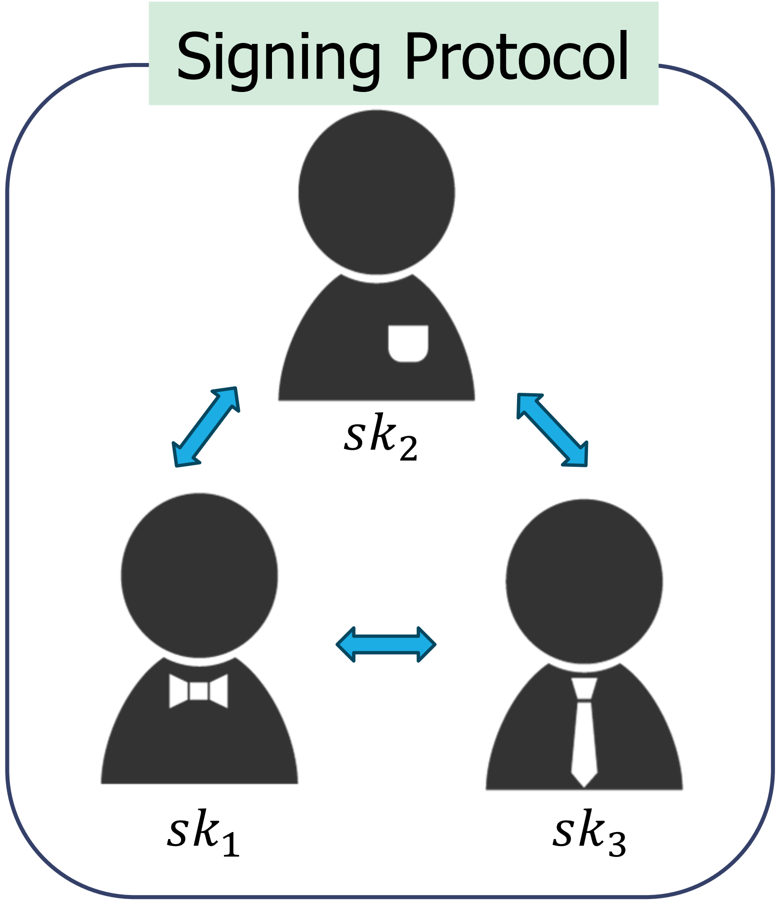


Increase communication cost during signing protocol 😞

Deferred IA Protocol

Delay the identification of misbehaving signers until the protocol aborts.



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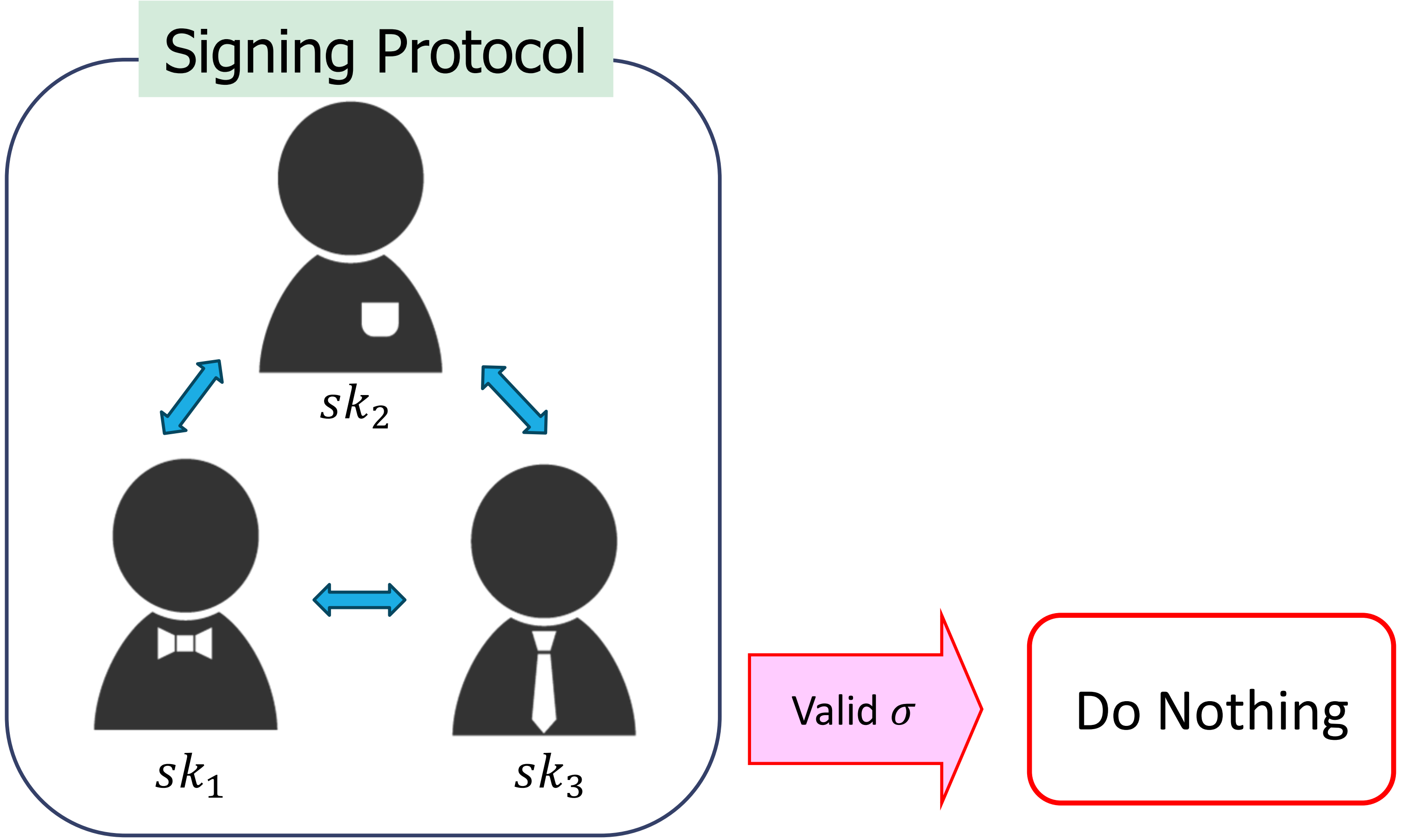

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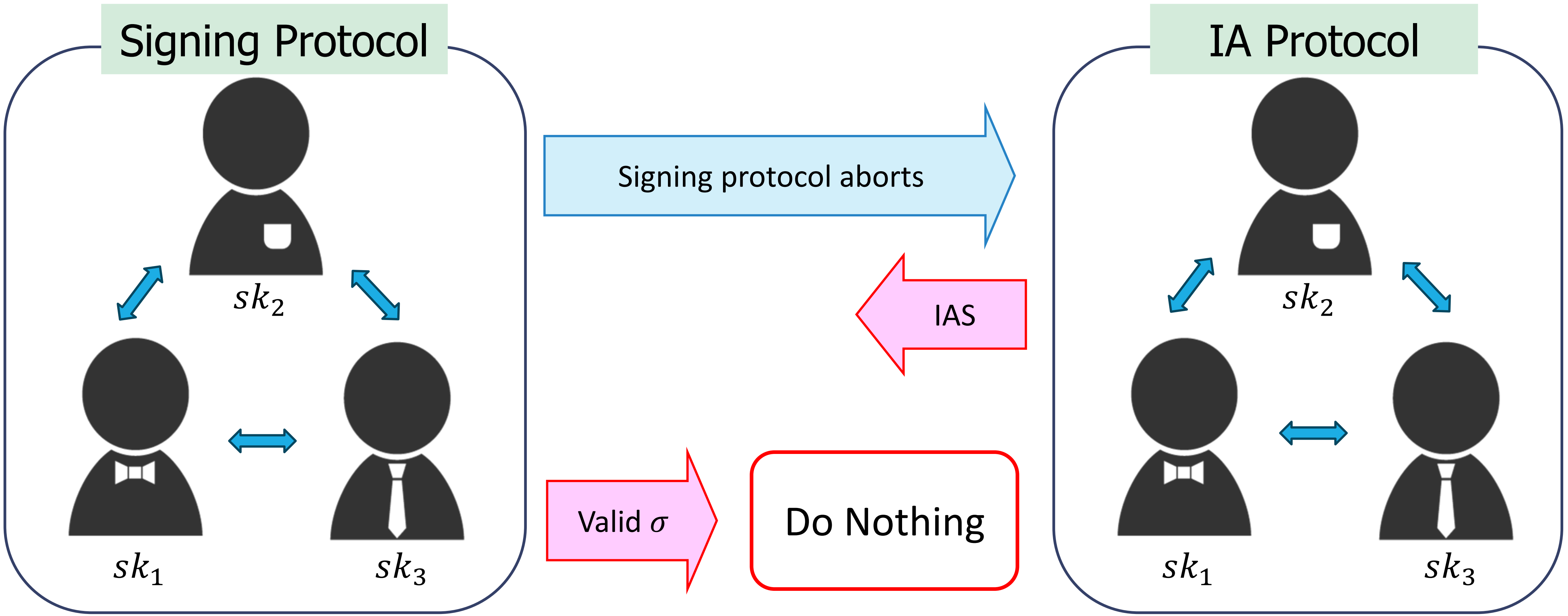

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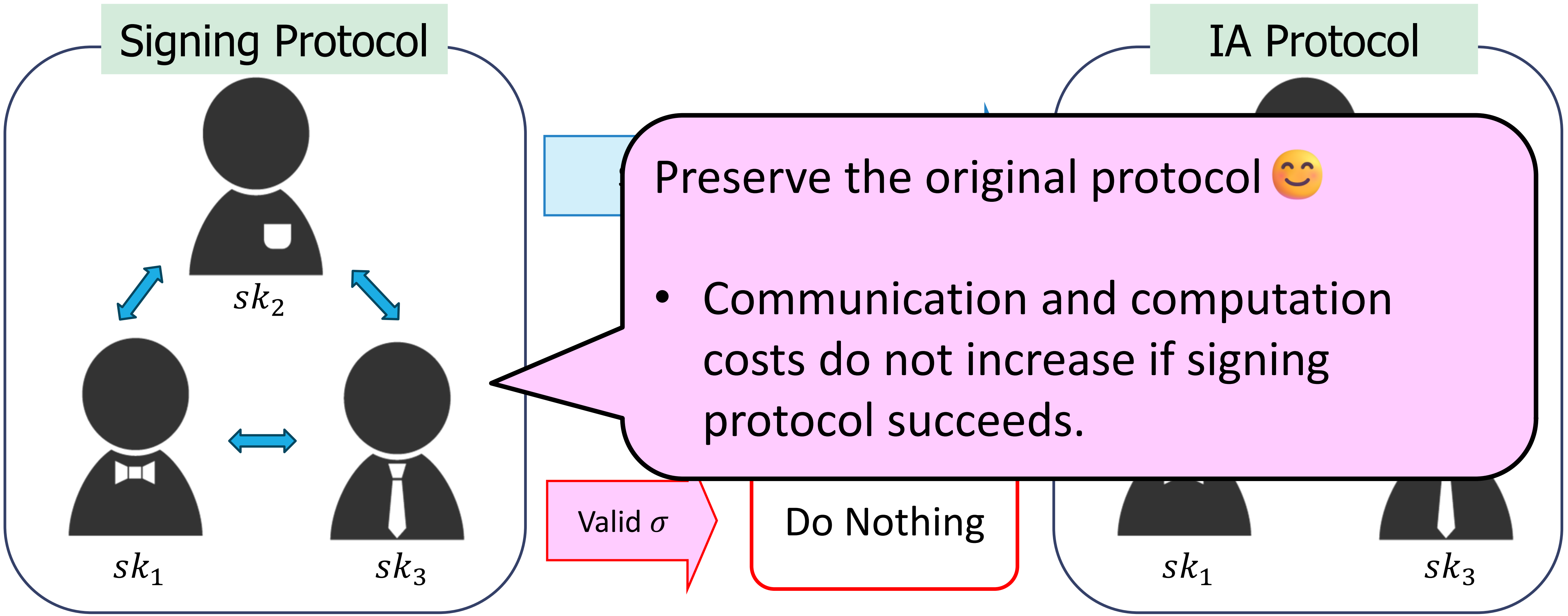

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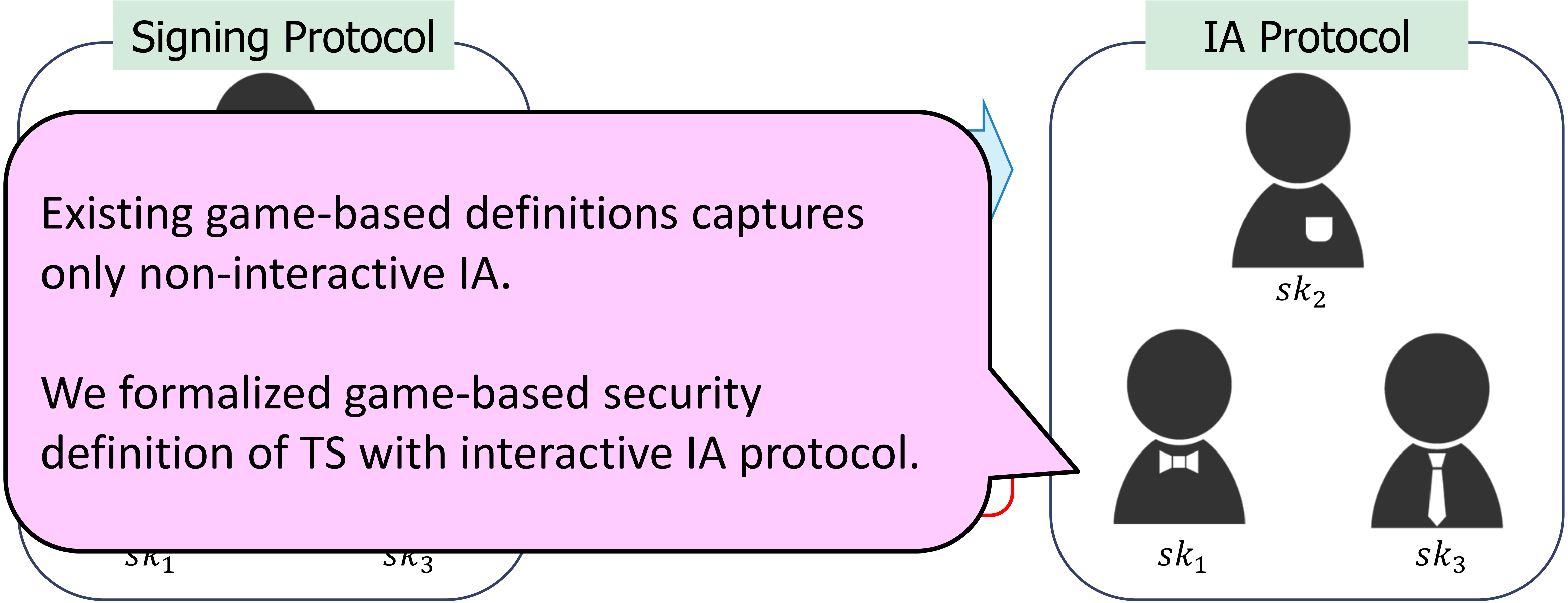

Existing game-based definitions captures only non-interactive IA.

We formalized game-based security definition of TS with interactive IA protocol.

Relations to be Proven via NIZK

Our IA protocol follows the approach using NIZK.

Relations to be proven:

(1) $\boldsymbol{r}_i$ is short

(2) $\boldsymbol{z}_i = c \cdot L_{SS,i} \cdot \boldsymbol{s}_i + \boldsymbol{r}_i + \Delta_i$

(3) $\Delta_i = \sum_j (\boldsymbol{m}_{i,j} - \boldsymbol{m}_{j,i})$

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(1)–(3): Algebraic

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(4): Non-Algebraic

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Algebraic: (1)–(3)

Non-Algebraic: (4)

Proving "mixed" relations is impractical 😞
How can we avoid this?

Bypassing Non-Algebraic Relation

Why is (4) $\boldsymbol{m}_{i,j} = H_{msk}\left(seed_{i,j}, ctnt_z\right)$ required?

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Our observation:
As long as each pair uses the same $\boldsymbol{m}_{i,j}$ even though it is not honestly generated, $\sum_i \Delta_i = 0$ holds.

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Idea: Ensure (★) outside of NIZK

How to Check (★)

Com: Lattice-based commitment scheme

1. For $j \in SS \setminus \{i\}$, compute $D_{i,j}^{(i)} \leftarrow Com(\boldsymbol{m}_{i,j}; \delta_{i,j})$ and $D_{j,i}^{(i)} \leftarrow Com(\boldsymbol{m}_{j,i}; \delta_{j,i})$ where $\delta_{i,j} = H_{rnd}(seed_{i,j}, ctnt_z)$, $\delta_{j,i} = H_{rnd}(seed_{j,i}, ctnt_z)$.
   Broadcast $\left(D_{i,j}^{(i)}, D_{j,i}^{(i)}\right)_{j \in SS \setminus \{i\}}$

Deterministic

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2. Broadcast $\left(seed_{i,j}^{(i)}, seed_{j,i}^{(i)}\right)$ for j s.t. $D_{i,j}^{(i)} \neq D_{i,j}^{(j)}$ or $D_{j,i}^{(i)} \neq D_{j,i}^{(j)}$

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Inconsistent Mask

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Inconsistent Mask

$H_{msk}\left(seed_{k,\ell}^{(k)}, ctnt_z\right)$ $H_{rnd}\left(seed_{k,\ell}^{(k)}, ctnt_z\right)$

3. Check $D_{k,\ell}^{(k)} = Com\left(\boldsymbol{m}_{k,\ell}^{(k)}; \delta_{k,\ell}^{(k)}\right)$ and $C_{i,j} = H_{seed}(seed_{k,\ell}^{(k)})$
   If not, k is misbehavior.

Generated in KeyGen

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Thanks to binding of commitment scheme, we can ensure that each pair uses the same masks!

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How to Check (★)

heme

Revealing seeds does not harm the security because seeds for honest pairs are not revealed.

$\leftarrow Com(\boldsymbol{m}_{i,j}; \delta_{i,j}$

$t_z), \delta_{j,i} = H_{rnd}($

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(4)' $D_{i,j}^{(i)} = Com(\boldsymbol{m}_{i,j}; \delta_{i,j})$

Algebraic !!

<u>Lattice-based ZK-SNARK combining LNP[LNP22] + LaBRADOR[BS23]</u>
which is sketched in prior works [BS23,ADDG24].
We formally analyze security of this approach in a modular manner.

Performance

	$\lvert\sigma\rvert$	Com Cost in Signing	$\lvert SS\rvert$	Availability
Traccoon[dPKM+24]	12.7	28.2	T	-
Traccoon-IA	12.7	28.2	T	IA $60+6.4\cdot T$

Same cost in signing protocol

Simple add-on

Thank you for your attention!!

Future Works:

- Does our technique work on related lattice-based schemes using masking mechanism [EKT24], [KRT24], [BKL+25].
- Distributed Key Generation for our scheme

Independent and Concurrent Work:

[dPENP] Del Pino et al. "Simple and Efficient Lattice Threshold Signatures with Identifiable Aborts"

- IA for a variant of TRaccoon based on new short secret sharing technique
- Non-interactive IA
- Efficient when the number of signers or corruption threshold is small