Risky Traitor Tracing and New Differential Privacy Negative Results

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Hardness of Non-Interactive Differential Privacy from One-Way Functions

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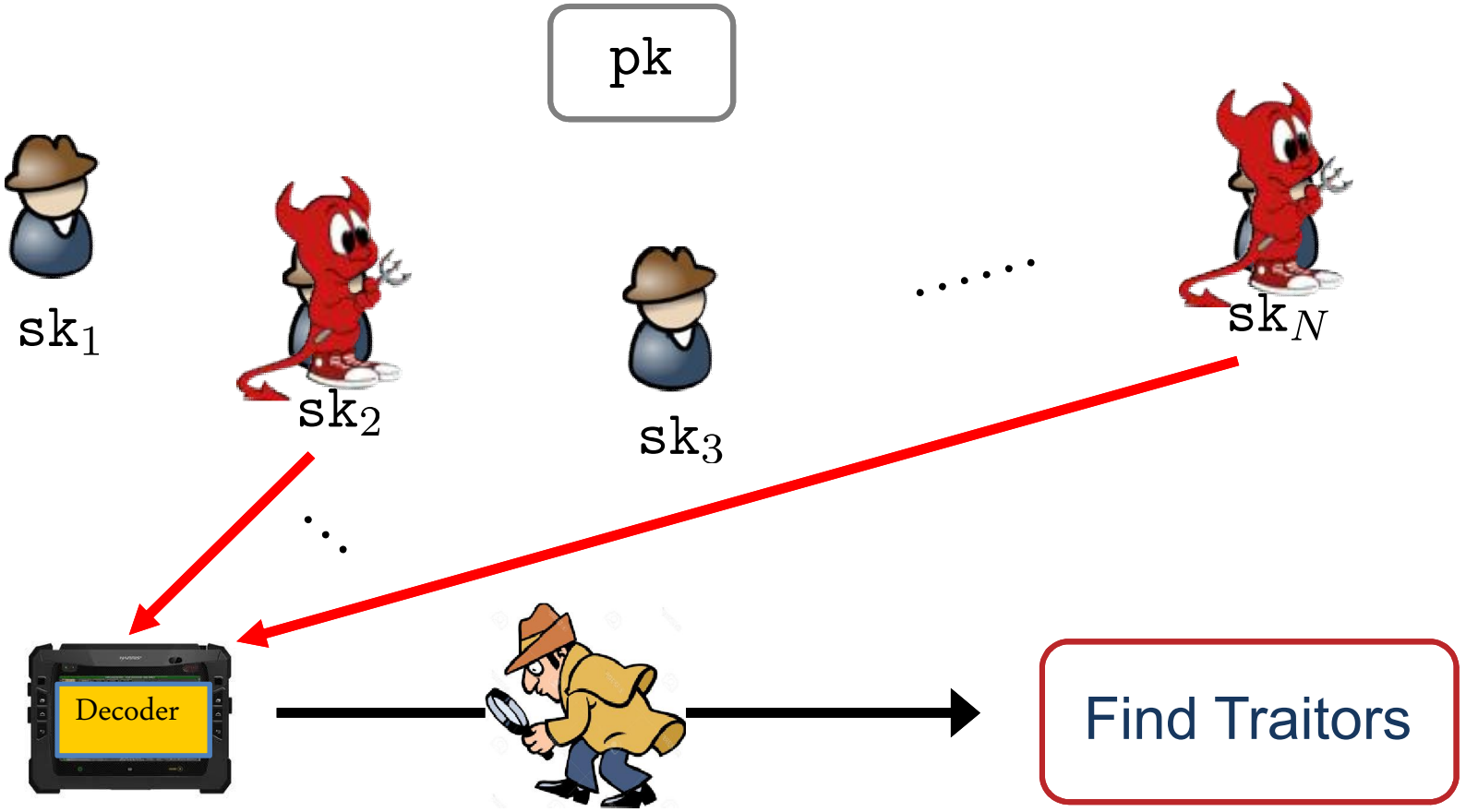
Traitor Tracing [Chor-Fiat-Naor 94]



Key Challenges:
(1) Obfuscated Decoder
(2) Collusions

Tracing Algorithms

$\mathtt{Setup}(1^\lambda, 1^N) \to (\mathtt{msk}, \mathtt{pk}, (\mathrm{sk}_1, \ldots, \mathrm{sk}_N))$

$\mathtt{Enc}(\mathtt{pk}, m \in \mathcal{M}) \to \mathtt{ct}$

$\mathtt{Dec}(\mathtt{sk}, \mathtt{ct}) \to m \in \mathcal{M}$

$\mathtt{Trace}^D(\mathtt{msk}, 1^y, m_0, m_1) \to T \subseteq [1, N]$

$$\texttt{ExptTT}_{\mathcal{A},\epsilon}(\lambda)$$

$$1^N$$

$$\texttt{Setup}(1^\lambda, 1^N) \to (\texttt{msk}, \texttt{pk}, (\texttt{sk}_1, \ldots, \texttt{sk}_N))$$

$$\texttt{pk}$$

$$S \subseteq [1, N]$$

$$\texttt{sk}_i : i \in S$$

$$D, m_0, m_1$$

$$T \leftarrow \texttt{Trace}^D(\texttt{msk}, 1^{1/\epsilon(\lambda)}, m_0, m_1)$$

(1) No false trace: $\Pr[\exists i : i \in T, i \notin S] = \text{negl}(\lambda)$

(2) Catch: $\Pr[T \neq \emptyset] \geq \Pr[D \ \epsilon\text{-distinguishes} \ (m_0, m_1)]$

It's About the Ciphertext Size!

PKE: $N \cdot \mathrm{poly}(\lambda)$

Bilinear Maps [Boneh-Sahai-Waters06,Boneh-Waters06…]: $\sqrt{N} \cdot \mathrm{poly}(\lambda)$

Functional Encryption/iO[GGHRSW13,Boneh-Zhandry14]: $\mathrm{poly}(\lambda, \lg N) = \mathrm{poly}(\lambda)$

Can we get better efficiency from standard assumptions if we relax tracing requirement?

(* Subsequent to this work, G-Koppula-Waters gave an LWE-based standard TT scheme matching FE/iO-based efficiency.)

Relaxing Tracing

Standard Traitor Tracing

(1) No false trace: $\Pr[\exists i : i \in T, i \notin S] = \mathrm{negl}(\lambda)$

(2) Catch: $\Pr[T \neq \emptyset] \geq \Pr[D \ \epsilon\text{-distinguishes} \ (m_0, m_1)]$

$f(\cdot,\cdot)$-*Risky* Traitor Tracing

(1) No false trace: $\Pr[\exists i : i \in T, i \notin S] = \mathrm{negl}(\lambda)$

(2) Catch: $\Pr[T \neq \emptyset] \geq f(\lambda, n) \cdot \Pr[D \ \epsilon\text{-distinguishes} \ (m_0, m_1)]$

(Main) Results [G-Koppula-Russell-Waters]

Theorem. Under simple assumptions over bilinear groups, we build a secure *f-risky Traitor Tracing* scheme with $|ct|$ ciphertext size.

$$\forall\ k > 0, \quad f(\lambda, N) = \frac{k}{N} \quad \Longrightarrow \quad |\mathtt{ct}| = O(k \cdot \lambda)$$

Theorem. Secure $\frac{1}{N}$ - *risky Traitor Tracing* scheme implies differential privacy negative results.

Remaining Talk

Part I: Risky Traitor Tracing

Part II: Differential Privacy Negative Results (Luke)

Standalone Risky TT Applications

- Persistent decoder setting
  - Periodic key refreshes, decoder must work across cycles
  - Catching probability can be amplified
- Resource constrained settings
  - Get best possible tracing w/ 10 KB ciphertext overhead
- Risk averse attackers
  - Deterrence against attackers if traitors heavily penalized
  - Heavy penalty vs. Low catching probability

Framework for Risky TT – Mixed Bit Matching Encryption

$\mathtt{Setup}(1^\lambda, 1^\ell) \to (\mathtt{pk}, \mathtt{msk})$

$\mathtt{Enc\text{-}PK}(\mathtt{pk}, m) \to \mathtt{ct}$

$\mathtt{Enc\text{-}SK}(\mathtt{msk}, m, \mathbf{y} \in \{0,1\}^\ell) \to \mathtt{ct}$

$\mathtt{KeyGen}(\mathtt{msk}, \mathbf{x} \in \{0,1\}^\ell) \to \mathtt{sk}$

$\mathtt{Dec}(\mathtt{sk}, \mathtt{ct}) \to m$

$$g(\mathbf{x}, \mathbf{y}) = \bigwedge_{i \in [\ell]} x_i \vee y_i$$

Correctness Enc-PK: Dec outputs m

Correctness Enc-SK: Dec outputs m iff $g(\boldsymbol{x}, \boldsymbol{y}) = 1$

Mixed Bit Matching Security

Security: 3 properties

PK/SK CT Hiding → Distinguish

$\texttt{Enc-PK}(\texttt{pk}, m)$ vs $\texttt{Enc-SK}(\texttt{msk}, m, 1^{\ell})$

CT Hiding → Distinguish

$\texttt{Enc-SK}(\texttt{msk}, m_0, \mathbf{y}_0)$ vs $\texttt{Enc-SK}(\texttt{msk}, m_1, \mathbf{y}_1)$

Key Hiding → Distinguish

$\texttt{KeyGen}(\texttt{msk}, \mathbf{x}_0)$ vs $\texttt{KeyGen}(\texttt{msk}, \mathbf{x}_1)$

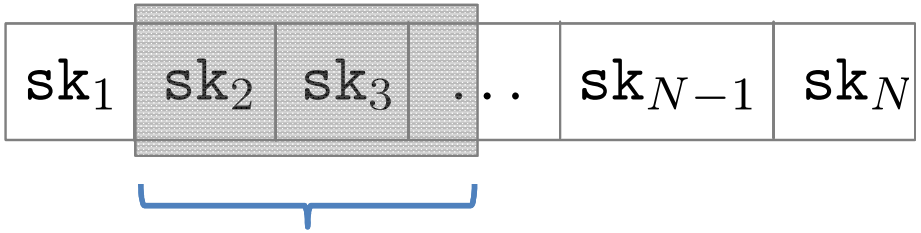
Transformation to Risky TT

$\underline{\mathtt{Setup}(1^\lambda, 1^N) \to (\mathtt{pk}, \mathtt{msk}, \{\mathtt{sk}_i\}_{i \le N})}$

$\mathtt{mBME.Setup}(1^\lambda, 1^{k+1}) \to (\mathtt{mbme.pk}, \mathtt{mbme.msk})$

$$\mathtt{pk} = \mathtt{mbme.pk}$$

$$\mathtt{msk} = \mathtt{mbme.msk}$$

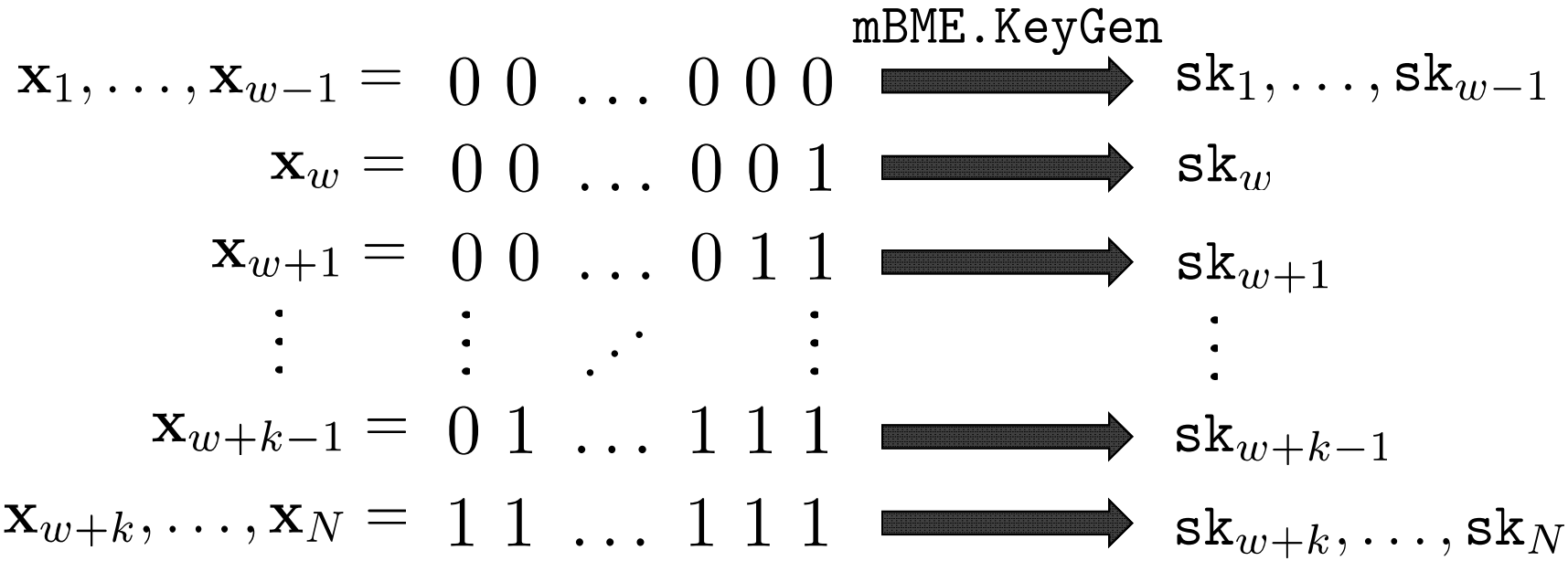


Transformation to Risky TT

$\underline{\texttt{Setup}(1^\lambda, 1^N) \to (\texttt{pk}, \texttt{msk}, \{\texttt{sk}_i\}_{i \le N})}$

$\texttt{mBME.Setup}(1^\lambda, 1^{k+1}) \to (\texttt{mbme.pk}, \texttt{mbme.msk})$

Choose random target window start location $w \in [N - k]$



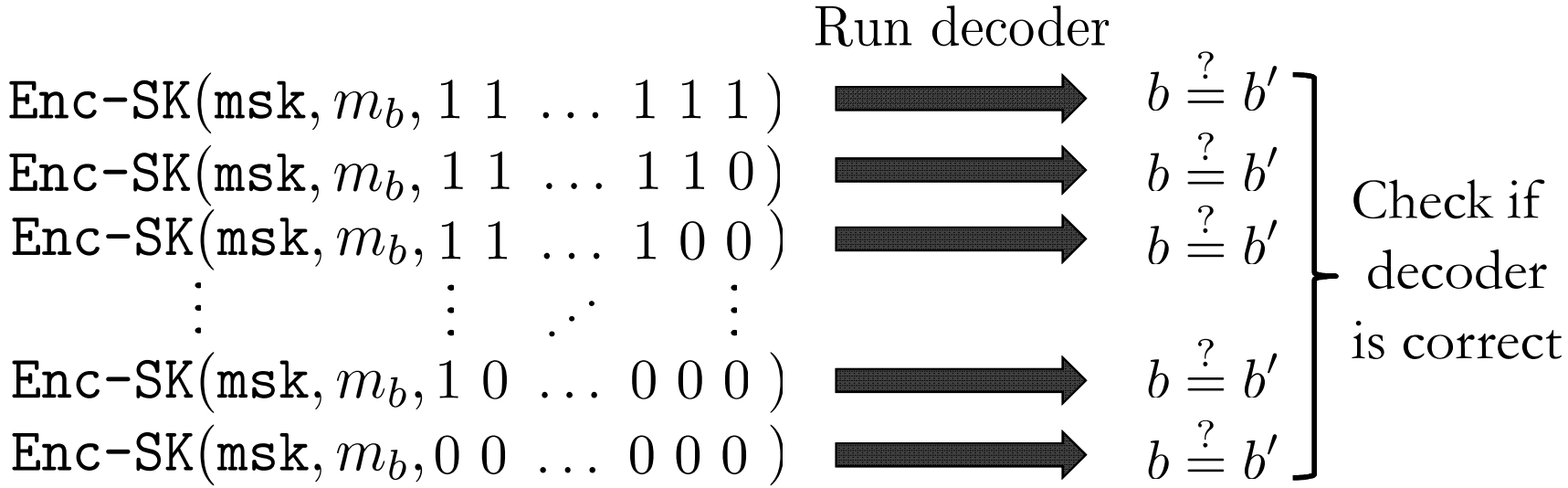
Transformation to Risky TT

$\underline{\texttt{Enc}(\texttt{pk}, m) = \texttt{mBME.Enc-PK}(\texttt{pk}, m)}$

$\underline{\texttt{Dec}(\texttt{sk}, \texttt{ct}) = \texttt{mBME.Dec}(\texttt{sk}, \texttt{ct})}$

Transformation to Risky TT

$\underline{\texttt{Trace}^{D}(\texttt{msk}, 1^{y}, m_0, m_1) \to T}$



Do this poly times

Transformation to Risky TT

$\underline{\texttt{Trace}^{D}(\texttt{msk}, 1^{y}, m_0, m_1) \rightarrow T}$

Successful decryption probability

$$\texttt{Enc-SK}(\texttt{msk}, m_b, 1\ 1\ \ldots\ 1\ 1\ 1) \Rightarrow p_1$$
$$\texttt{Enc-SK}(\texttt{msk}, m_b, 1\ 1\ \ldots\ 1\ 1\ 0) \Rightarrow p_2$$
$$\texttt{Enc-SK}(\texttt{msk}, m_b, 1\ 1\ \ldots\ 1\ 0\ 0) \Rightarrow p_3$$
$$\vdots \qquad \vdots \qquad \ddots \qquad \vdots$$
$$\texttt{Enc-SK}(\texttt{msk}, m_b, 1\ 0\ \ldots\ 0\ 0\ 0) \Rightarrow p_{k+1}$$
$$\texttt{Enc-SK}(\texttt{msk}, m_b, 0\ 0\ \ldots\ 0\ 0\ 0) \Rightarrow p_{k+2}$$

If p_i and p_{i+1} are noticeably far, then add index $(i + w - 1)$ to the set T

Missing Pieces and Other Results

- Security proof of the transformation
  - Significantly departs from existing proof techniques for TT
- Building Mixed Bit Matching Encryption from Bilinear Maps
- Generic risky amplification
  - Improving success probability of tracing

Remaining Talk

Part I: Building Risky Traitor Tracing

Part II: Differential Privacy Negative Results (Luke)


Q&A