Efficient Public-Key Cryptography with Bounded Leakage and Tamper Resilience

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(Provable Secure) Crypto before Physical Attacks
Crypto with Physical Attacks

Leak Attacks [Koc96],
Crypto with Physical Attacks

Leak Attacks [Koc96], Tampering Attacks [BDL97]
(Minimal) Related Works

Memory Circuit

[GLMMR04] [IPSW06]

Restricted [DPW10,BK03] Bounded [DFMV13]
(Minimal) Related Works

Definitions of Bounded-Tamper (and Leakage) Resilience,
Identification Scheme and Signatures (ROM),
CCA-Secure PKE.

- Memory
  - [GLMMR04]
  - Restricted
    - [DPW10,BK03]
  - Bounded
    - [DFMV13]

- Circuit
  - [IPSW06]
Our Contributions

- BTL Signature Scheme.

  Example. The Imp. result of [GLMMR03] does not hold.
Our Contributions

- **BTL Signature Scheme.**

  Example. The Imp. result of [GLMMR03] does not hold.

- **BLT CCA Public Key Encryption.**
  Naor-Yung paradigm, what about Cramer-Shoup?
Section 2

BLT-CCA PKE
\((t, \ell)\)-BLT IND-CCA PKE:
(t, ℓ)-BLT IND-CCA PKE:

- \(A\) leaks before challenge \(ℓ\) bits;
- \(A\) instantiates before challenge \(t\) oracles

\[(\text{for } ℓ + t \leq |sk| - \omega(\log k))\]
The Scheme of [QL13]: Building Blocks

Complete: For $c \in V$, $\text{Pub}^{pk}(c, w) = \Lambda^{sk}(c)$.

Sound: For $c \in C \setminus V$, any $\text{pk} = \bar{\mu}^{sk}(\cdot)$:

$\tilde{H}_{\infty}(K := \Lambda^{sk}(c) | \text{pk}) \geq -\log \epsilon$.

Set Membership Problem.

$\delta$-extractor $\tilde{H}_{\infty}(X | Z) \geq \delta$, we have $(Z, S, \text{Ext}(X, S)) \approx (Z, S, U)$. 

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The Scheme of [QL13]: Building Blocks

\( \epsilon \)-Hash Proof System

- **Complete**: For \( c \in \mathcal{V} \), \( \widetilde{\Lambda}_{sk}(c) = \Lambda_{sk}(c) \).
- **Sound**: For \( c \in \mathcal{C} \setminus \mathcal{V} \), any \( pk = \mu(sk) \):
  \[ \widetilde{\mathbb{H}}_{\infty}(K := \Lambda_{sk}(c)|pk) \geq -\log \epsilon \]
- **Set Membership Problem**.
The Scheme of [QL13]: Building Blocks

\( \epsilon \)-Hash Proof System

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- **Set Membership Problem**.

\( \delta \)-extractor

\[ \tilde{H}_\infty(X | Z) \geq \delta, \text{ we have } (Z, S, \text{Ext}(X, S)) \approx (Z, S, U) \]
\[ LF_\phi : \mathcal{T} \times \mathcal{X} \rightarrow \mathcal{Y} \]
The Scheme of [QL13]: Building Blocks, Pt.2

\( \ell-\text{(OT-)Lossy Filter} \)

\[ LF_\phi : \mathcal{T} \times \mathcal{X} \rightarrow \mathcal{Y} \]
$\ell$-(OT-)Lossy Filter

$LF_\phi : \mathcal{T} \times \mathcal{X} \to \mathcal{Y}$
$\ell$-(OT-)Lossy Filter

$\mathcal{L}_F : \mathcal{T} \times \mathcal{X} \rightarrow \mathcal{Y}$

- **Losiness:** $|\{•\}| \geq 2^\ell$
- **Indistinguishable:** $\approx \in \{0, 1\}^* \times \mathcal{T}_c$
The Scheme of [QL13]: Building Blocks, Pt.2

$$\ell-(OT-)\text{Lossy Filter}$$

$$\text{LF}_\phi : \mathcal{T} \times \mathcal{X} \rightarrow \mathcal{Y}$$

- **Losiness:** $$|\{\bullet\}| \geq 2^\ell$$
- **Indistinguishable:** $$\text{tag} \approx \text{tag} \in \{0, 1\}^* \times \mathcal{T}_c$$
- **Evasiveness:** It is hard to forge $$t^*_c$$ lossy even given one lossy tag.
The Scheme of [QL13]:

\[
\begin{align*}
\Pi &\quad \text{LF}_\phi \\
\phi &\quad t_a \\
C &\quad t_c \\
S &\quad \Phi
\end{align*}
\]

\[
\begin{align*}
P_{ub_{pk}} &\quad K &\quad \text{Ext} \\
m &\quad \text{H}_\infty (K^*|\n_{\phi}, C^*, L) \geq -\log \varepsilon - |L| \\
&\quad \text{H}_\infty (K^*|\n_{\phi}, C^*, L, \Pi) \geq -\log \varepsilon - |L| - \ell
\end{align*}
\]
The Scheme of [QL13]:

\[ H_\infty(K_\ast|_{pk}, C_\ast, L) \geq -\log \varepsilon - |L| \]

\[ H_\infty(K_\ast|_{pk}, C_\ast, L, \Pi) \geq -\log \varepsilon - |L| - \ell \]
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Reduce Tampering to Leakage

\[ \text{Dec}_{T(sk)} \approx O_{\text{aux}} \]

- \( aux = L(sk) \)
- Interact \textbf{unbounded} with \( \text{Dec}_{T(sk)} \), while \( aux \) small and \textbf{bounded}.
Let $\tilde{sk} = T(sk)$, leak $\mu(\tilde{sk})((C, S, \Phi), t_c, \Pi)$ fully define $K$. Execute Decryption.

$C \not\in V$ Depend on $H_\infty(\Lambda \tilde{sk}(C) | View = v)$.

If big then output $\bot$; If small then leak $\tilde{sk}$ and run Dec $\tilde{sk}$.

Yeah, but what do big and small even mean? I would tell you, if I had time..
Let $\tilde{sk} = T(sk)$, leak $\mu(\tilde{sk})$

$((C, S, \Phi), t_c, \Pi)$
Let \( \tilde{sk} = T(sk), \text{ leak } \mu(\tilde{sk}) \)

\[
((C, S, \Phi), t_c, \Pi)
\]

\( C \in \mathcal{V} \)

\((C, \mu(\tilde{sk})) \) fully define \( K \). Execute Decryption.
Let $\tilde{sk} = T(sk)$, leak $\mu(\tilde{sk})$

$$((C, S, \Phi), t_c, \Pi)$$

---

$C \in \mathcal{V}$

$(C, \mu(\tilde{sk}))$ fully define $K$. Execute Decryption.

---

$C \notin \mathcal{V}$

Depend on $H_{\infty}(\Lambda_{\tilde{sk}}(C)|\textbf{View} = v)$.

- If big then output $\bot$;
- If small then leak $\tilde{sk}$ and run Dec$\tilde{sk}$. 
Let \( \tilde{sk} = T(sk) \), leak \( \mu(\tilde{sk}) \)

\[ ((C, S, \Phi), t_c, \Pi) \]

\[ C \in \mathcal{V} \]

\((C, \mu(\tilde{sk}))\) fully define \( K \). Execute Decryption.

\[ C \notin \mathcal{V} \]

Depend on \( \mathbb{H}_\infty(\Lambda_{\tilde{sk}}(C) | View = v) \).
- If big then output \( \perp \);
- If small then leak \( \tilde{sk} \) and run \( \text{Dec}_{\tilde{sk}} \).

Yeah, but what do big and small even mean?
Let $\tilde{sk} = T(sk)$, leak $\mu(\tilde{sk})$

$$((C, S, \Phi), \ t_c, \Pi)$$

### $C \in \mathcal{V}$

$(C, \mu(\tilde{sk}))$ fully define $K$. Execute Decryption.

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Depend on $\mathbb{H}_\infty(\Lambda_{\tilde{sk}}(C)|\text{View} = \nu)$.
- If big then output $\bot$;
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Yeah, but what do big and small even mean? I would tell you, if I had time..
Mathemagical!!

\[ \beta = s - \log \varepsilon, \quad s = \log |SK| \]
\[ \alpha = \log |PK| \]

- We pay approx \( \alpha + \beta \) bits of leakage for each tampering oracle.

\[ t = \frac{s}{\alpha + \beta} \]
Mathemagical!!

\[
\beta = s - \log \varepsilon, \quad s = \log |SK|
\]
\[
\alpha = \log |PK|
\]

- We pay approx \( \alpha + \beta \) bits of leakage for each tampering oracle.

\[
 t = \frac{s}{\alpha + \beta}
\]

We can instantiate the HPS using RSI.
Open Problems

- Is the tampering rate \( O(1/k) \) inherent?
- A better Hash Proof System?
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- A better Hash Proof System?

Thank You!