Innovative R&D by NTT

Improving Practical UC-Secure Commitments based on the DDH Assumption

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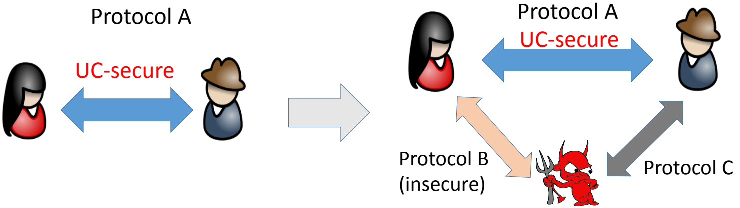
Agenda

Motivation: Efficient UC-Secure Protocols

Universal composability (UC) framework guarantees that if a protocol is proven secure in the UC framework, it remains secure even if it is run concurrently with *arbitrary* protocols.



Weak spot: The lack of *efficient* instantiations.

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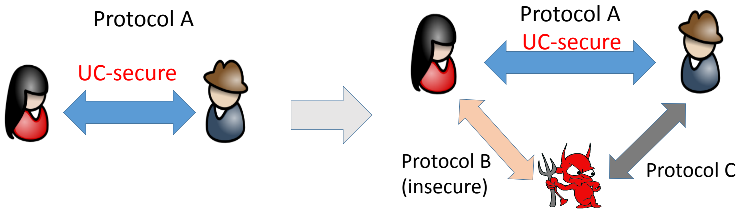

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More efficient (static/adaptively) UC-secure commitment scheme enables *more efficient* constructions of (static/adaptively) UC-secure (MPC) protocols.

UC Commitments [CF01]

Informally, a commitment scheme is UC-secure if the **hiding** and **binding** properties hold *even if it runs concurrently with arbitrary protocols*.

For a technical reason, we make a commitment scheme **extractable, equivocal and con-current non-malleable**. Then, prove that it is universally composable.

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Static and Adaptive UC Security

- **Static UC-security** = UC security against **static corruption**.
- **Adaptive UC-security** with/out erasure = UC security against **adaptive corruption** with/out erasure.

- **Static Corruption**: An adversary should decide to corrupt parties only before a protocol starts.
- **Adaptive Corruption**: An adversary may corrupt parties at any timing.
- **Secure Erasure**: Honest parties can securely erase their unnecessary inner states.

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1 Motivation

2 Previous Work

3 Our Result

4 Idea of Improvement

5 Proof Outline (Static case)

6 Static to Adaptive

7 Conclusion

Previous Work

- [CF01]
  - Seminal paper. Non-interactive, reusable, adaptively UC-secure without erasure (= fully-equipped).
- [CLOS02]
  - From general assumption, fully-equipped but Inefficient.
- [DN02, DG03, NFT12, Fuj14]
  - **Efficient adaptively** UC-secure without erasure (based on N^d modulus for $d \geq 2$). [NFT12]: one-time. [Fuj14]: fully-equipped.
- [Lin11, BCPV13], [FLM11]
  - **Efficient adaptively** UC-secure *with erasure* (based on prime order groups). [FLM11]: non-interactive (based on *bilinear* groups).
- [GIKW14, DDGN14, CDD$^+$15, FJNT16, CDD$^+$16]
  - Fast, statistic UC-secure.
- [DSW08]
  - Global UC-secure.
- [HM04, CJS14]
  - Random oracle model.

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Efficient Adaptively UC-secure with Erasure

So far, [BCPV13] provides the most efficient adaptively UC-secure commitment scheme.

- [Lin11]: Static and adaptively UC-secure interactive commitment schemes based on an *arbitrary* cyclic group on which the DDH assumption holds.
- [BCPV13]: Improvement of [Lin11]. Reduce round, communication, and computational complexities. Fix a bug of Lindell's adaptively UC-secure commitment scheme.

[BCPV13]: Blazy, Chevalier, Pointcheval, and Vergnaud (ACNS2013).

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Our Result

Further improve efficiency of [BCPV13] *in both static and adaptive cases* under the *same* assumption.

- Improvement: CRS size, communication complexity, and computational complexity.
- Round complexity: same as [BCPV13].
- As the previous works, work on an arbitrary cyclic group on which the DDH assumption holds true.

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Comparison

Table: Comparison among the UC commitments based on the DDH assumption (along with the collision resistant hash functions).

Schemes	CRS	Communication Complexity	Computational Complexity	Rounds Com/Decom	Security
Lin11 [Lin11, § 3]	$7\lvert\mathbb{G}\rvert$	$10\lvert\mathbb{G}\rvert + 4\kappa$	$27T^{\mathsf{exp}}(\mathbb{G})$	1/4	Static
Lin11 [Lin11, § 4]	$8\lvert\mathbb{G}\rvert$	$12\lvert\mathbb{G}\rvert + 6\kappa$	$36T^{\mathsf{exp}}(\mathbb{G})$	5/1	Adaptive
BCPV13 [BCPV13, § 5.1]	$7\lvert\mathbb{G}\rvert$	$9\lvert\mathbb{G}\rvert + 3\kappa$	$22T^{\mathsf{exp}}(\mathbb{G})$	1/3	Static
BCPV13 [BCPV13, § 5.3]	$7\lvert\mathbb{G}\rvert$	$10\lvert\mathbb{G}\rvert + 4\kappa$	$26T^{\mathsf{exp}}(\mathbb{G})$	3/1	Adaptive
Ours (Static)	$5\lvert\mathbb{G}\rvert$	$7\lvert\mathbb{G}\rvert + 3\kappa$	$18T^{\mathsf{exp}}(\mathbb{G})$	1/3	Static
Ours (Adaptive)	$5\lvert\mathbb{G}\rvert$	$7\lvert\mathbb{G}\rvert + 3\kappa$	$18T^{\mathsf{exp}}(\mathbb{G})$	3/1	Adaptive

Note: All *adaptively* UC-secure commitments above assume *secure erasure*.

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UC Commitments are required

Extractable

A simulator can extract the value that a corrupted party commits to.

Equivocal

A simulator can produce commitments that can be opened to any value.

When executing extraction and equivocation, the simulator is not allowed to rewind the adversary.

Concurrently Non-Malleable

An adversary must not be able to create commitments that are related to commitments generated by honest parties.

High-Level Idea (Static) by Lindell

- The commit phase:
  - Use PKE. Send $\mathrm{CT} = \mathbf{E}_{pk}(x; w)$ as a commitment (for extractability).
- The open phase:
  - Open x and prove that CT *is a proper ciphertext of* x in a zero-knowledge manner (for equvocality).
- For concurrent Non-Malleability:
  - Trivial solusion: Use IND-CCA secure (= static UC secure) PKE and UC zero-knowledge.
  - Problem: UC zero-knowledge proofs are constructed from UC commitments.

Lindell's Static UC-Secure Commitments

- Trivial solusion : IND-CCA PKE (for commitment) + UC zero-knowledge proofs (of knowledge) (for opening).
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  - (*): 3-round implementation using trapdoor commitment + Sigma protocol (by BCPV).
    - = [Dam00]: Efficient concurrent zero-knowledge in auxiliary string model.

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Can replace IND-CCA PKE with IND-PCA PKE ($\star$).

$\star$: The Short Cramer-Shoup encryption [ABP15].

Our Observation

- IND-CCA PKE is overkill in both static and adaptive cases.
  - **Can replace IND-CCA PKE with IND-PCA PKE**, where IND-PCA means semantical security against *plaintext checkable* attacks [ABP15].
- In the adaptive case, **two trapdoor commitments (w.r.t. two independent public-keys) can be reduced to a single trapdoor commitment**.

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Our static UC-Secure Commitment

Alice (Committer)		Bob (Receiver)
	The Commit Phase	
Commit to x by sending $\mathrm{CT} = \mathbf{E}^{pca}_{\mathrm{pk}^{\mathrm{enc}}}(x; w)$ (cf. BCPV13: IND-CCA)	$\xrightarrow{\mathrm{CT}}$	
	The Open Phase	
Open to x as follows: $\psi = \mathrm{Com}^{\mathrm{tc}}_{\mathrm{pk}^{\mathrm{tc}}}(\alpha; r_{\mathrm{tc}})$	$\xrightarrow{x,\ \psi}$	
	$\xleftarrow{\beta}$	$\beta \leftarrow \{0,1\}^{\lambda_{\mathrm{ch}}}$.
Compute γ using w. Reveal α with r_{tc}.	$\xrightarrow{\alpha, r_{\mathrm{tc}}, \gamma}$	Accept if (α, β, γ) is valid on (x, CT).

The open phase: a proof that "CT is a proper ciphetext of x."

Proof Outline

Environment $\mathcal{Z}$'s view: $(\mathsf{CT}, x, \rho, \mathsf{CT}', x', \rho', \tilde{x})$.

Table: The man-in-the-midle attack in the hybrid games

Games	Left Interaction Alice $\xrightarrow{(\mathsf{CT}, x, \rho)}$ Eve (corrupted)	Right Interaction Eve (corrupted) $\xrightarrow{(\mathsf{CT}', x', \rho')}$ Bob	Output to $\mathcal{Z}$ $\xrightarrow{\tilde{x}}$ $\mathcal{Z}$ (Env.)
G_0 (Real)	Commit phase: $\mathsf{CT} = \mathbf{E}(x; w)$ Open phase: x and real proof ρ on the (true) statement T	Commit phase: CT' Open phase: x' and proof ρ' on the statement T'	$\tilde{x} = x'$
G_1	Commit phase: $\mathsf{CT} = \mathbf{E}(x; w)$ Open phase: x and real proof ρ on the (true) statement T	Commit phase: CT' Open phase: x' and proof ρ' on the statement T'	$\tilde{x} = \mathbf{D}_{sk}(\mathsf{CT}')$
G_2	Commit phase: $\mathsf{CT} = \mathbf{E}(x; w)$ Open phase: x and simulated proof ρ on the (true) statement T	Commit phase: CT' Open phase: x' and proof ρ' on the statement T'	$\tilde{x} = \mathbf{D}_{sk}(\mathsf{CT}')$
G_3 (Ideal)	Commit phase: $\mathsf{CT} = \mathbf{E}(0; w)$ Open phase: x and simulated proof ρ on the (false) statement T	Commit phase: CT' Open phase: x' and proof ρ' on the statement T'	$\tilde{x} = \mathbf{D}_{sk}(\mathsf{CT}')$

Statement T: CT is a proper ciphertext of x, i.e., $\mathsf{CT} = \mathbf{E}(x)$.
Statement T': CT' is a proper ciphertext of x', i.e., $\mathsf{CT}' = \mathbf{E}(x')$.

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$G_0 \stackrel{c}{\approx} G_1$: By soundness property of ordinary zero-knowledge protocols and correctness of PKE.

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$G_1 \equiv G_2$: By perfect straight-line zero-knowledge simulator of [Dam00].

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$G_2 \overset{c}{\approx} G_3$: By IND-PCA secure PKE. Construct A that breaks IND-PCA PKE using $\mathcal{Z}$ and corrupted Eve.

Proof between G_2 and G_3

Tricky part: A is *only given the plaintext-checkable (PCA) oracle, not the decryption oracle*.

The decryption oracle seems to be needed, because the simulator needs the decryption of ciphertexts from Eve. However, **it is not true**.

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- Case1 (Eve **always opens commitments correctly**). Then A can perfectly **simulate $\mathcal{Z}$'s views** in G_2 and G_3, according as given $\mathrm{CT} = \mathbf{E}(x)$ and $\mathbf{E}(0)$ **without knowing** sk. Then, "the advantage of A" = "the advantage of $\mathcal{Z}$".

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- Case 2 (Eve **opens commitment wrongly**). Then A must play in G_3, because **in G_2, Eve cannot fool the receiver**. A can check if she fooled the receiver or not, **using the PCA oracle**. Then, A can halt and say "I am playing in G_3".

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Static to Adaptive

- Lindell's Idea: Switch the order of the messages (For soundness, commits to CT at the beginning).
- (BCPV's bug fix: Commit to (x, CT), not only CT to fix the statement for proof beforehand.)
- Our observation: CT and α (the first message of the Sigma protocol) can be committed to in the same commitment.

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- Our observation: CT and α (the first message of the Sigma protocol) can be committed to in the same commitment.
  - *Can reduce communication and computational complexities*.

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Our adaptively UC-Secure Commitment

Alice (Committer) | Bob (Receiver)

The Commit Phase

$\mathsf{CT} = \mathbf{E}^{pca}_{\mathsf{pk}^{\mathsf{enc}}}(x; w)$

$\psi = \mathsf{Com}^{\mathsf{tc}}_{\mathsf{pk}^{\mathsf{tc}}}((x, \mathsf{CT}, \alpha); r_{\mathsf{tc}})$ $\xrightarrow{\psi}$

$\xleftarrow{\beta}$ $\beta \leftarrow \{0,1\}^{\lambda_{\mathsf{ch}}}$.

Compute γ using w.

Erase w. $\xrightarrow{\mathsf{CT}}$

The Open Phase

Reveal (α, γ) with r_{tc}. $\xrightarrow{x,\ \alpha, r_{\mathsf{tc}}, \gamma}$ Accept if (α, β, γ) is valid on (x, CT).

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Conclusion

- We further improve *efficiency* of [BCPV13] *in both static and adaptive-with-erasure cases*.
- As with [Lin11, BCPV13], our proposals work on *an arbitrary cyclic group* on which the DDH assumption holds true.
- Our *adaptive* one is the *most efficient* adaptively UC-secure (with erasure) commitment scheme.

Thank you!

(Nearly) full version available at ePrint Archive 2016/656.

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