Authenticated Key Exchange and Signatures with Tight Security in the Standard Model

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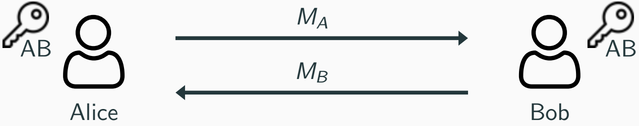
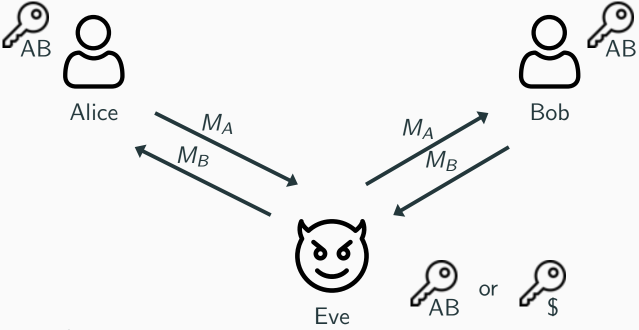
Authenticated Key Exchange



Authenticated Key Exchange



The adversary

- controls the network
- adaptively corrupts long-term keys
- reveals secret states
- reveals real session keys

Security Goals

- Authenticity
- Key Indistinguishability

Provable Security

Security is modelled as a game between a challenger and an adversary.

Security reduction

- We turn adversary an $\mathcal{A}$ against the scheme into an adversary $\mathcal{B}$ that solves a computationally hard problem.

A reduction is called *tight* if $\mathcal{A}$ and $\mathcal{B}$

- have about the same advantage.
- run in about the same time.

Relevance: tells us how to choose system parameters

Difficulties in Proving Tight AKE

The commitment problem

- Need to be able to answer *key-reveal* and *test* queries for all sessions
- Need to avoid guessing the test session(s)

Long-term key reveals and tightly-secure signatures

- Signatures to achieve explicit authentication
- Need to answer adaptive *corrupt* queries and output secret signing keys
- At the same time: extract the solution to a hard problem from a signature forgery

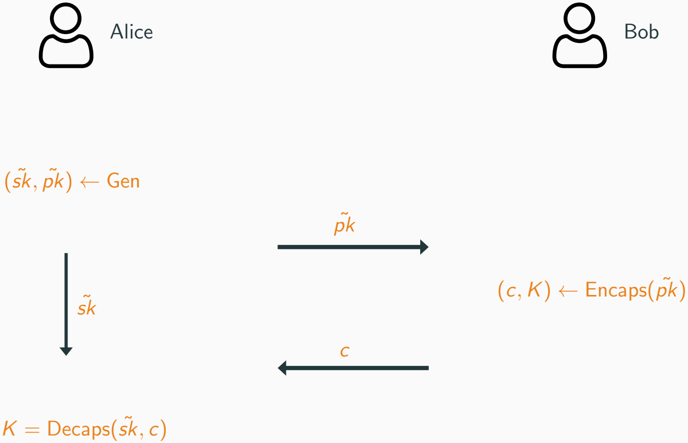
Comparison with Previous Work

	Efficient	Standard Model	Tight Proof	Ephemeral State Reveal
BHJKL15	✗	✓	✓	✗
GJ18	(✓)	✗	✓	✗
CCGJJ19	✓	✗	✗	✗
LLGW20	(✗)	✓	✓	✗
JKRS21	(✓)	✗	✓	✓
This work	(✓)	✓	(✓)*	✓

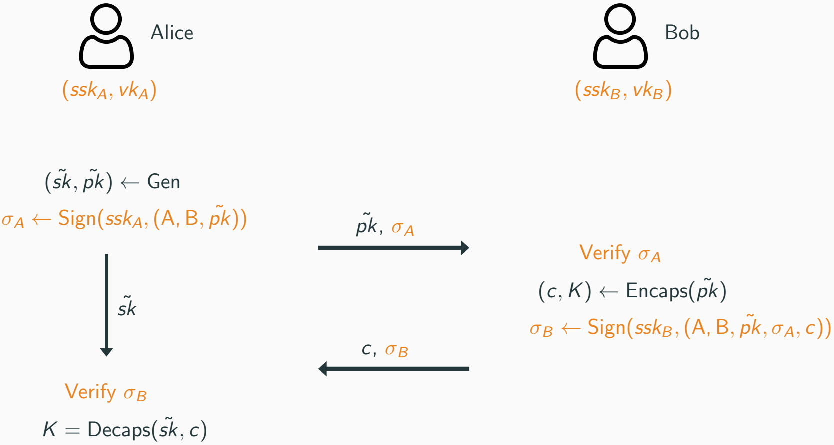
*Non-tight only with respect to a symmetric primitive when allowing state reveals

Our AKE Protocol

AKE[KEM]


Alice
Bob
$(\tilde{sk}, \tilde{pk}) \leftarrow \mathsf{Gen}$
$\tilde{pk}$
$\tilde{sk}$
$(c, K) \leftarrow \mathsf{Encaps}(\tilde{pk})$
c
$K = \mathsf{Decaps}(\tilde{sk}, c)$

AKE[KEM, SIG]



Alice

(ssk_A, vk_A)

Bob

(ssk_B, vk_B)

$(\tilde{sk}, \tilde{pk}) \leftarrow \mathsf{Gen}$

$\sigma_A \leftarrow \mathsf{Sign}(ssk_A, (\mathsf{A}, \mathsf{B}, \tilde{pk}))$

$\tilde{pk},\ \sigma_A \longrightarrow$

Verify σ_A

$(c, K) \leftarrow \mathsf{Encaps}(\tilde{pk})$

$\sigma_B \leftarrow \mathsf{Sign}(ssk_B, (\mathsf{A}, \mathsf{B}, \tilde{pk}, \sigma_A, c))$

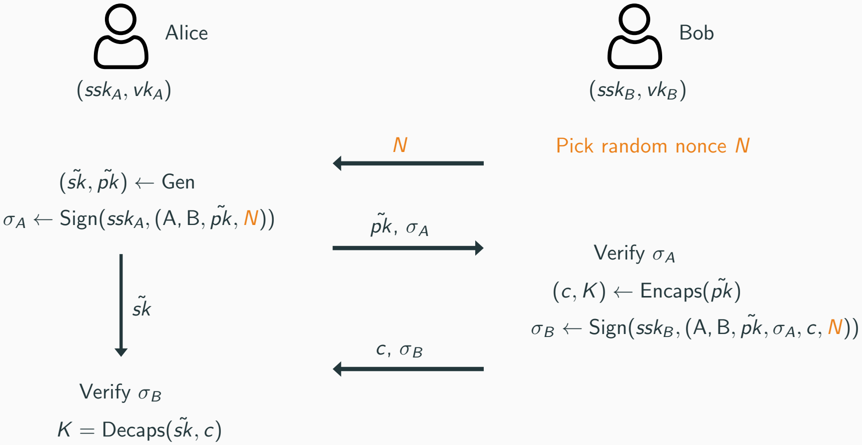
$\longleftarrow c,\ \sigma_B$

$\downarrow \tilde{sk}$

Verify σ_B

$K = \mathsf{Decaps}(\tilde{sk}, c)$

AKE[KEM, SIG, Nonce]



Alice

(ssk_A, vk_A)

Bob

(ssk_B, vk_B)

Pick random nonce N

N

$(\tilde{sk}, \tilde{pk}) \leftarrow \mathsf{Gen}$

$\sigma_A \leftarrow \mathsf{Sign}(ssk_A, (\mathsf{A}, \mathsf{B}, \tilde{pk}, N))$

$\tilde{pk}, \; \sigma_A$

$\tilde{sk}$

Verify σ_A

$(c, K) \leftarrow \mathsf{Encaps}(\tilde{pk})$

$\sigma_B \leftarrow \mathsf{Sign}(ssk_B, (\mathsf{A}, \mathsf{B}, \tilde{pk}, \sigma_A, c, N))$

$c, \; \sigma_B$

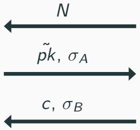
Verify σ_B

$K = \mathsf{Decaps}(\tilde{sk}, c)$

Security Requirements

KEM:	MU-MC-CCA	AKE[KEM, SIG]
	MU-SC-CCA	AKE[KEM, SIG, Nonce]

- Many AKE sessions
  → requires security for many key pairs
- AKE[KEM, SIG]: The adversary can replay ephemeral public key
  → many-ciphertext security
- AKE[KEM, SIG, Nonce]: A fresh nonce prevents replays
  → single-ciphertext security
- The adversary can choose ciphertexts when impersonating a user
  → requires to decrypt them to simulate keys correctly



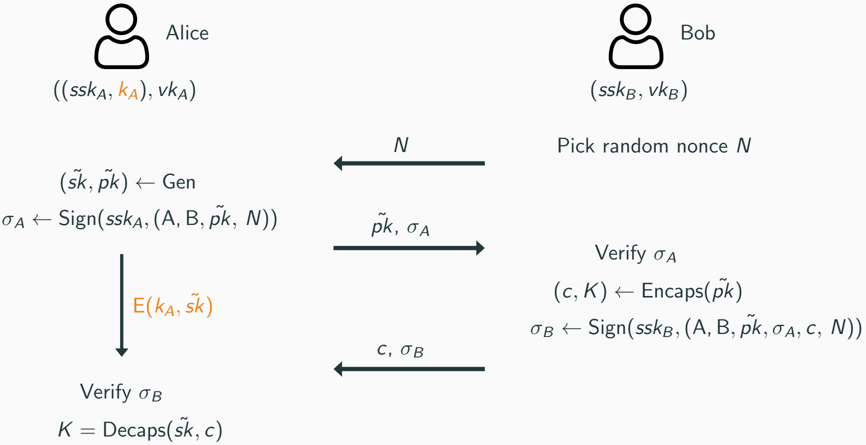
Security Requirements

Signature Scheme: $\mathsf{MU\text{-}EUF\text{-}CMA}^{\mathsf{corr}}$

- Each user has a long-term key pair
  → multi-user security
- Users authenticate each other explicitly
  → requires unforgeability of messages
- The adversary can adaptively corrupt users
  → need to provide the secret signing key

Security against State Reveal

AKE[KEM, SIG, Nonce, SE]



Alice

$((ssk_A, k_A), vk_A)$

Bob

(ssk_B, vk_B)

Pick random nonce N

N

$(\tilde{sk}, \tilde{pk}) \leftarrow \mathsf{Gen}$

$\sigma_A \leftarrow \mathsf{Sign}(ssk_A, (\mathsf{A}, \mathsf{B}, \tilde{pk}, N))$

$\tilde{pk}, \sigma_A$

Verify σ_A

$(c, K) \leftarrow \mathsf{Encaps}(\tilde{pk})$

$\sigma_B \leftarrow \mathsf{Sign}(ssk_B, (\mathsf{A}, \mathsf{B}, \tilde{pk}, \sigma_A, c, N))$

$\mathsf{E}(k_A, \tilde{sk})$

c, σ_B

Verify σ_B

$K = \mathsf{Decaps}(\tilde{sk}, c)$

Enhanced Security Requirements

Observation: The adversary must learn k_A and $\mathrm{E}(k_A, \tilde{sk})$ to obtain $\tilde{sk}$.
$\rightarrow$ Trivial attack, no test session.

But: we need to simulate correctly!

Yet another commitment problem

- After a state reveal, we don't know whether the adversary will later *corrupt* the user or *test* the session.
- Need to know all ephemeral secret key hidden inside the state.

Enhanced Security Requirements

KEM: additional algorithm $\mathsf{Encaps}^*(sk) \to (c^*, K^*)$

- $\mathsf{Encaps} \approx_c \mathsf{Encaps}^*$ for many key pairs, even given secret keys
- $(pk, \mathsf{Decaps}(sk, c), c^*, K^*) \approx_s (pk, \mathsf{Decaps}(sk, c), c^*, \$)$

We show how to build such a KEM using universal$_2$ Hash Proof Systems based on (M)DDH.

Symmetric Encryption: standard CPA security

Tightly-Secure Signatures

Tightly-Secure Signature Schemes

Goal: MU-EUF-CMA$^{\text{corr}}$ security

- Previous schemes: in the ROM or tree-based
- Efficient scheme by BHJKL15, but the proof is flawed

	tightly-secure affine MAC ⇒ tightly-secure SIG
BKP14	single-user setting
BHJKL15	multi-user setting
Our Work	multi-user setting with corruptions

We extend techniques of the LP19-HIBE to fix the scheme.

Still efficient: $|vk| = 1|\mathbb{G}|$, $|\sigma| = 5|\mathbb{G}|$ (instantiated under SXDH)

Summary

Contributions

- A new efficient and tight AKE protocol in the standard model.
- Security in a stronger security model, when allowing a non-tight reduction to the symmetric primitive.
- The first efficient and tightly-secure signature scheme supporting corruptions.

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