Careful with MAc-then-SIGn: A Computational Analysis of the EDHOC Lightweight Authenticated Key Exchange Protocol

Felix Günther and **Marc Ilunga**

July 5, 2023

Proliferation of low-powered devices

Image by Moritz Kindler

- Limited computing power
- Bandwidth constraints
- Plagued by vulnerabilities[1]

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- Missing satisfactory solutions
- EDHOC: a proposal by the IETF LAKE WG
- Use case: OSCORE[1] protocol (secure transport)
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  - Design similar to TLS1.3 and based on SIGMA[2]

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TLS 1.3 is a secure authenticated key exchange protocol

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(D)TLS 1.3 is not lightweight: up to 7x bandwidth usage

	Total protocol size (bytes)[1]
DTLS 1.3 (ECDHE)	880
TLS 1.3 (ECDHE)	789
EDHOC (STAT-STAT)	101

[1] Mattsson, Palombini, and Vučinić, *Comparison of CoAP Security Protocols*.

EDHOC in SIG-SIG Mode: An AKE based on Diffie-Hellman

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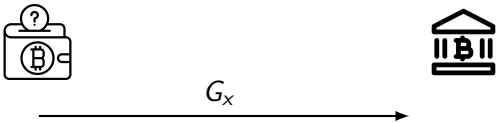

Initiator (1)

$x \xleftarrow{\$} \mathbb{Z}_q; G_x \leftarrow xG$

Responder(1)

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Initiator(2)

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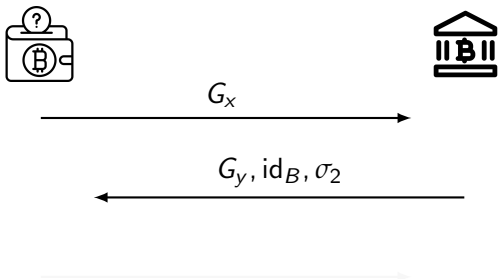

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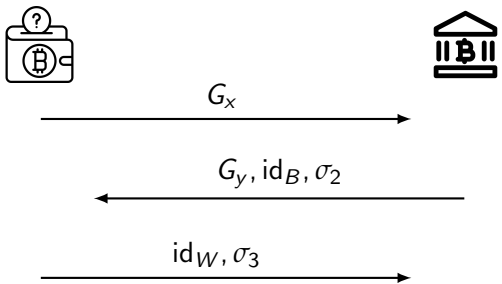

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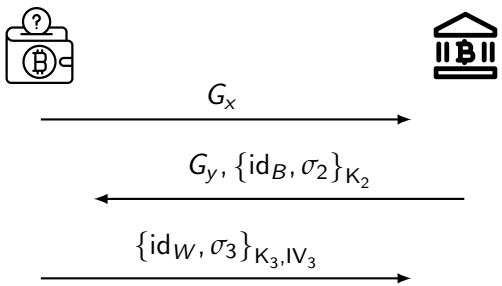
EDHOC in SIG-SIG Mode: An AKE with identity protection



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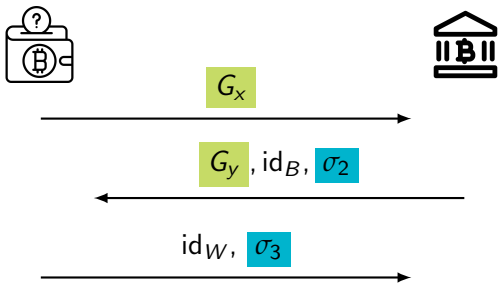

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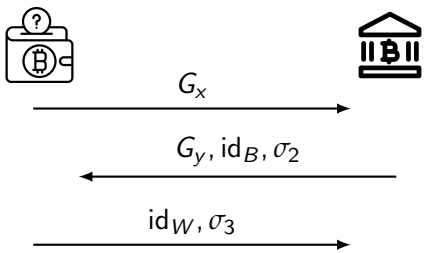
EDHOC SIG-SIG ≈ SIGMA: MAC "under" signature



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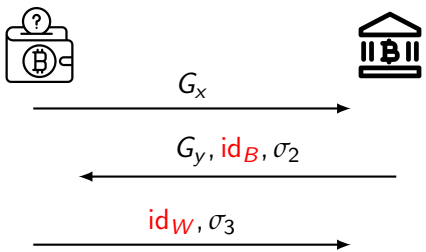
[9] Selander, Mattsson, and Palombini, *Ephemeral Diffie-Hellman Over COSE (EDHOC) – draft-ietf-lake-edhoc-17*, Section 3.5.3.

EDHOC SIG-SIG ≈ SIGMA: Abbreviated identities



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- size $\ll$ X.509 Cert
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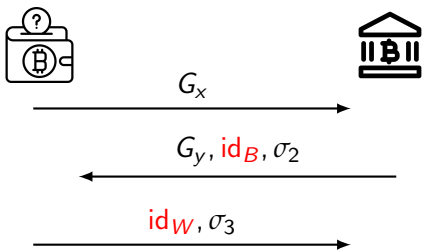

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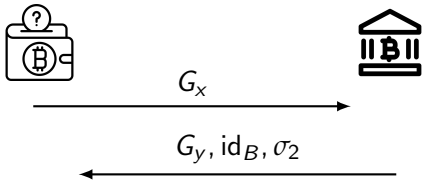

What if an attacker also uses id_B?
Duplicate Signature Key Selection attacks.

RunInit2

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foreach (U, pk_U) **with** $\mathrm{id}_U = \mathrm{id}_B$:

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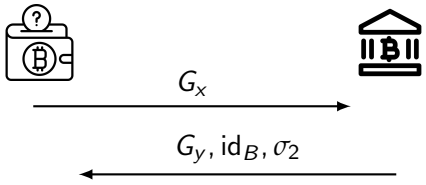

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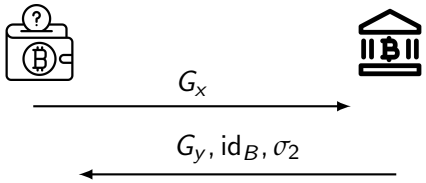

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DSKS vs SIGMA: identity misbinding (w/ strong attackers)

$\mathsf{id}_W, (pk_I, sk_I)$

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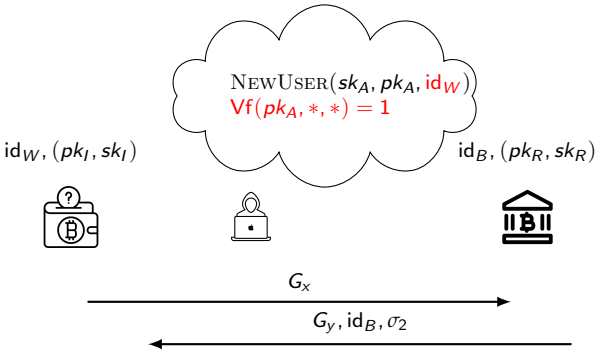

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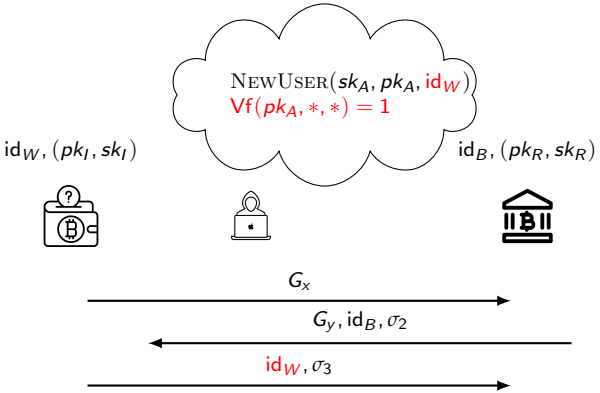

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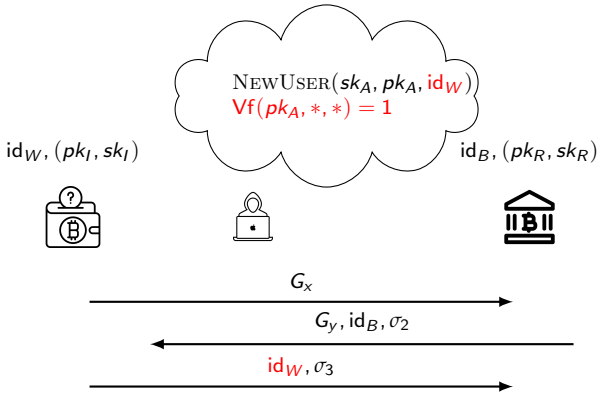

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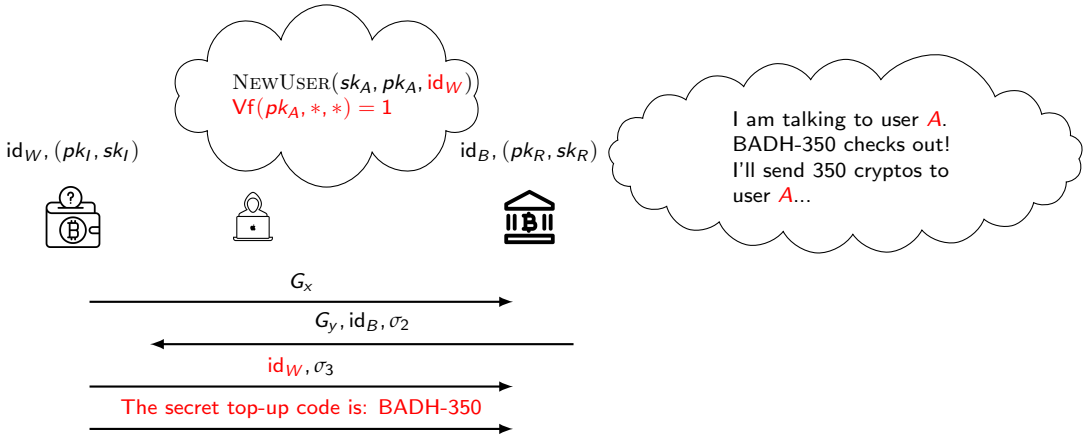

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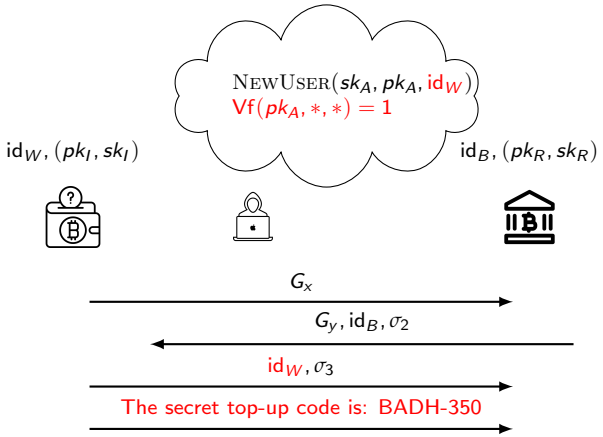

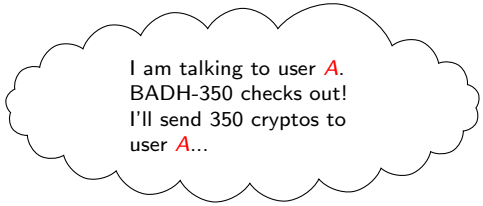

What about EDHOC?

EDHOC provides strong authentication guarantees even under colliding identifiers

- Assuming universal exclusive ownership[1] of the signature schemes
- S-UEO for signature scheme Σ (informal):
  - Key pair: $(pk, sk) \xleftarrow{\$} \Sigma.\mathsf{KGen}()$
  - Adversary $\mathcal{A}$ obtains $set(m_i, \sigma_i)$ (produced by sk)
  - Goal of $\mathcal{A}$: Produce (pk^*, m^*) s.t $\mathsf{Vf}(pk^*, m^*, \sigma_j) = 1$ and $pk \neq pk^*$
  - S-UEO $\implies$ $\mathcal{A}$ cannot succeed.

[1] Pornin and Stern, "Digital Signatures Do Not Guarantee Exclusive Ownership".

Security Model: Multi-Stage Key Exchange

Goals:

- Key indistinguishability
- Forward security
- Explicit authentication

Modeling contributions:

- NewUser(sk, pk, id)[1]

[1] Boyd et al., "ASICS: Authenticated Key Exchange Security Incorporating Certification Systems", (Inspired by).

MSKE Security of EDHOC SIG-SIG

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Let $\mathcal{A}$ be an MSKE adversary. For at most n_U users and n_S sessions, there exists adversaries $\mathcal{B}_j$ such that:

$$\begin{aligned}\mathrm{Adv}^{\mathrm{MSKE}}_{\mathcal{A}}(\text{EDHOC-Sig-Sig}) \leq \frac{{n_S}^2}{q} + \\ \mathrm{Adv}^{\mathrm{CR}}_{\mathcal{B}_4}(\mathsf{H}) + \\ 4n_S \left(\begin{array}{r} n_U \cdot \mathrm{Adv}^{\text{SUF-CMA}}_{\mathcal{B}_{I.2}}(\mathrm{Sig}) + \\ \mathrm{Adv}^{\text{S-UEO}}_{\mathcal{B}_{I.4}}(\mathrm{Sig}) \end{array} \right) + \\ 4n_S \left(\begin{array}{r} n_U \cdot \mathrm{Adv}^{\text{EUF-CMA}}_{\mathcal{B}_{II.A2}}(\mathrm{Sig}) + \\ \mathrm{Adv}^{\text{snPRF-ODH}}_{\mathcal{B}_{II.B2}}(\mathrm{Extract}) + \\ \mathrm{Adv}^{\mathrm{PRF}}_{\mathcal{B}_{II.B3}}(\mathrm{Expand}) \end{array} \right)\end{aligned}$$

Assumption	scheme	
Collision resistance	SHA2, Shake128	✓
SUF-CMA	Ed25519	✓
	ECDSA	✘
S-UEO	Ed25519	✓
	ECDSA	✘
EUF-CMA	Ed25519	✓
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PRF-ODH	HKDF.Extract	✓
	KMAC	(?)
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PRF-ODH	HKDF.Extract	✓
	KMAC	(?)
PRF	HKDF.Expand	✓
	KMAC	✓

ECDSA might be fine for EDHOC

- S-UEO ✘: EDHOC includes the pub key alongside messages to be signed (✓)
- SUF-CMA ✘: Implementations could use "canonical" signatures (✓ ?).

Positive collaboration with the LAKE working group

- Our work made several contributions to the EDHOC draft
- Numerous contributions to EDHOC by several other parties
- Reminiscent of development of TLS 1.3

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Questions: mail@felixguenther.info

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  - Design contributions to EDHOC
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