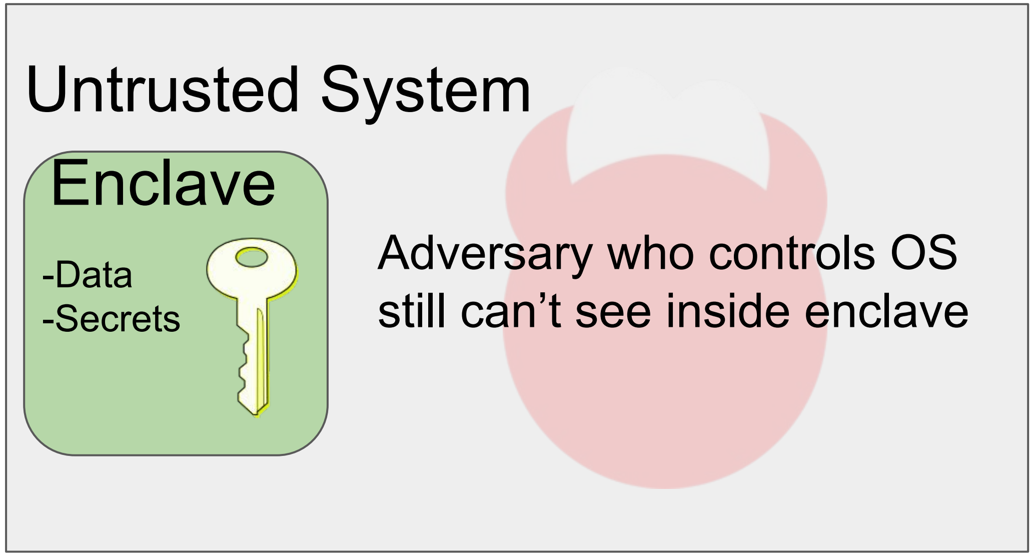
Post-Quantum EPID Signatures from Symmetric Primitives

Dan Boneh Saba Eskandarian Ben Fisch

Hardware Enclaves

A trusted component in an untrusted system

- Protected memory isolates enclave from compromised OS



Untrusted System

Enclave

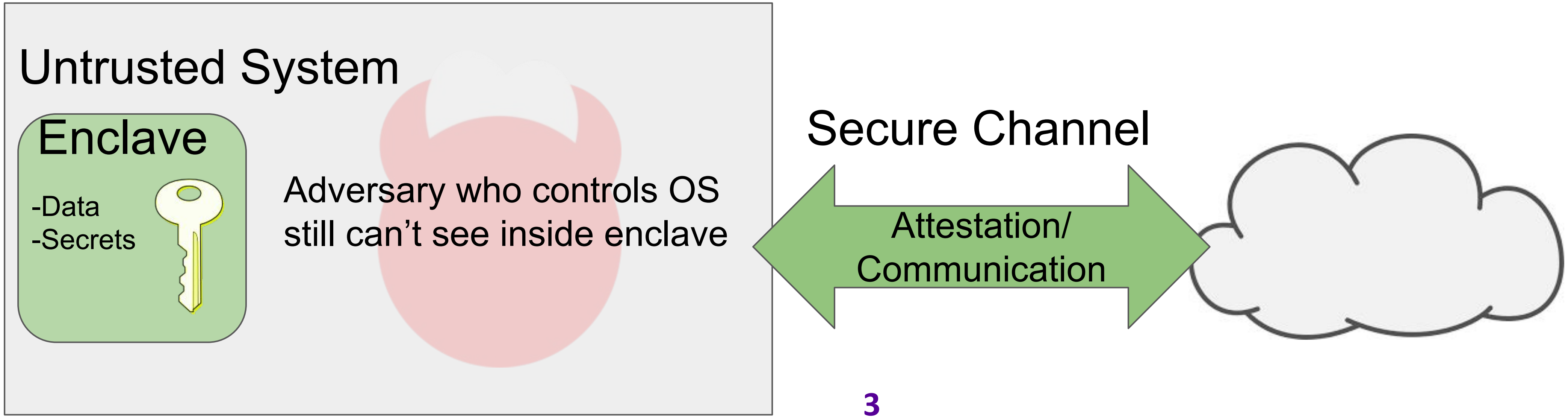
-Data
-Secrets

Adversary who controls OS still can’t see inside enclave

Hardware Enclaves

A trusted component in an untrusted system

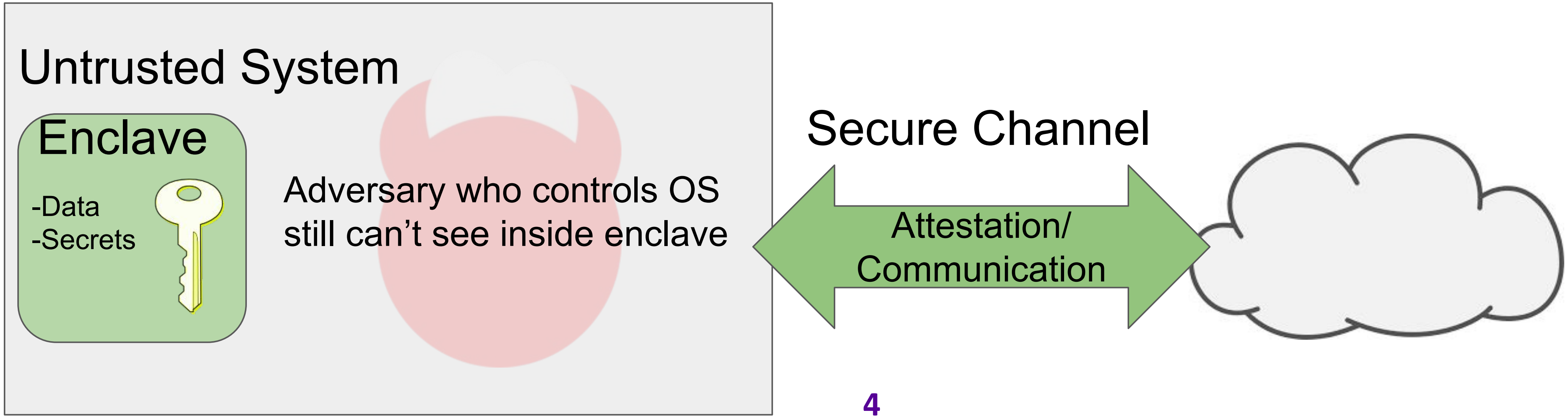
- Protected memory isolates enclave from compromised OS
- Proves authenticity via a process called *attestation*



Hardware Enclaves

A trusted component in an untrusted system

- Protected memory isolates enclave from compromised OS
- Proves authenticity via a process called *attestation*
  - Is it “post-quantum” secure?



Untrusted System

Enclave

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Adversary who controls OS
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Secure Channel

Attestation/
Communication

EPID Signatures [BL09]

Group signature-like primitive that provides two properties:

1. Signatures from any member of a group are indistinguishable from each other
2. Users can have their credentials revoked either by a blacklisted key or a blacklisted signature

Intel's EPID signature scheme relies on pairings and is not post-quantum secure

EPID Signatures [BL09]

$\mathtt{sk}_{\mathtt{i}}$, $\mathtt{cert}_{\mathtt{i}}$←`Join(...)` - interactive protocol between group member and manager to join group

σ←`Sign(gpk,`$\mathtt{sk}_{\mathtt{i}}$`,`$\mathtt{cert}_{\mathtt{i}}$`,m,SIG-RL)` - any user who has joined can sign a message anonymously as a group member

`1/0`←`Verify(gpk,m,KEY-RL,SIG-RL,`σ`)` - signatures only verify if signed by a valid, unrevoked group member

`KEY-RL’`←`RevokeKey(KEY-RL,`$\mathtt{sk}_{\mathtt{i}}$`)` - revoke a group member by key

`SIG-RL’`←`RevokeSig(SIG-RL,`σ`)` - revoke a group member by signature

Security properties: **Anonymity** and **Unforgeability**

EPID Signatures [BL09]

$\texttt{sk}_i, \texttt{cert}_i \leftarrow \texttt{Join}(\ldots)$ - interactive protocol between group member and manager to join group

$\sigma \leftarrow \texttt{Sign}(\texttt{gpk}, \texttt{sk}_i, \texttt{cert}_i, \texttt{m}, \texttt{SIG-RL})$ - any user who has joined can sign a message anonymously as a group member

$\texttt{1/0} \leftarrow \texttt{Verify}(\texttt{gpk}, \texttt{m}, \texttt{KEY-RL}, \texttt{SIG-RL}, \sigma)$ - signatures only verify if signed by a valid, unrevoked group member

$\texttt{KEY-RL}' \leftarrow \texttt{RevokeKey}(\texttt{KEY-RL}, \texttt{sk}_i)$ - revoke a group member by key

$\texttt{SIG-RL}' \leftarrow \texttt{RevokeSig}(\texttt{SIG-RL}, \sigma)$ - revoke a group member by signature

Security properties: **Anonymity** and **Unforgeability**

Our design goal: post-quantum security from **symmetric primitives only**

Picnic Signatures [CDGORRSZ17]

Uses ZKB++ MPC-in-the-head type proof system [IKOS07, GMO16]

i.e. proof of knowledge from symmetric primitives

High-level idea: Signature is proof of knowledge of preimage of a one-way function

e.g. I know sk such that f(sk)=y

Our Basic Approach [BMW03,CG04]

Join

User generates pk, sk

Group manager signs pk to form cert

Sign

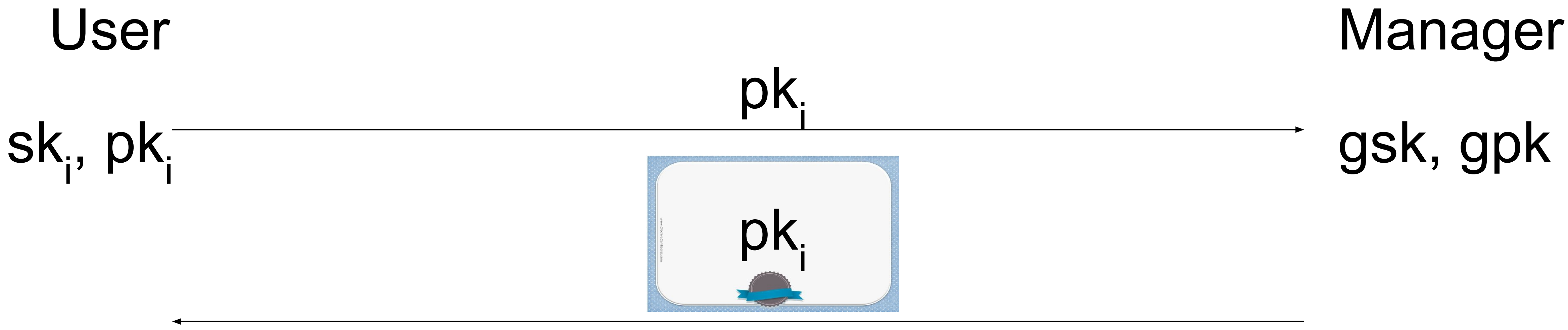
User signs message with sk

User publishes proof of knowledge of signature as σ

Additionally need to support revocation

Our Basic Approach [BMW03,CG04]

Join



User

Manager

sk_i, pk_i

pk_i

gsk, gpk

pk_i

Sign

s = Sign(sk_i, m)

Proof of Knowledge: I have a certificate on a key *sk** and a signature *s* on message *m* signed with *sk**

Post-Quantum EPID Signature

Join

User

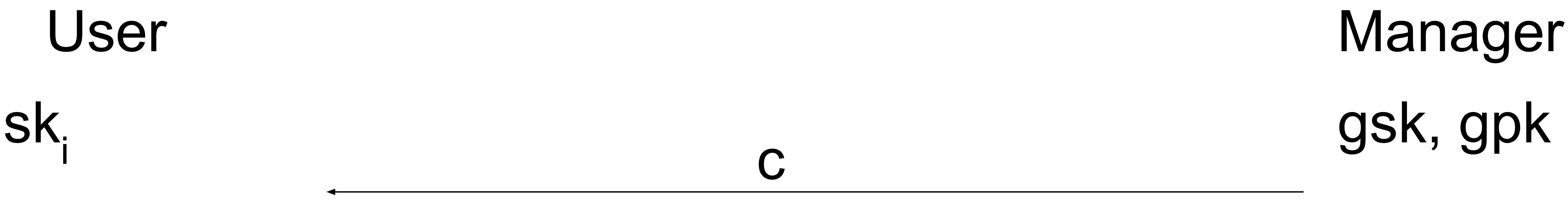
Manager

sk_i

gsk, gpk

Post-Quantum EPID Signature

Join



User

sk_i

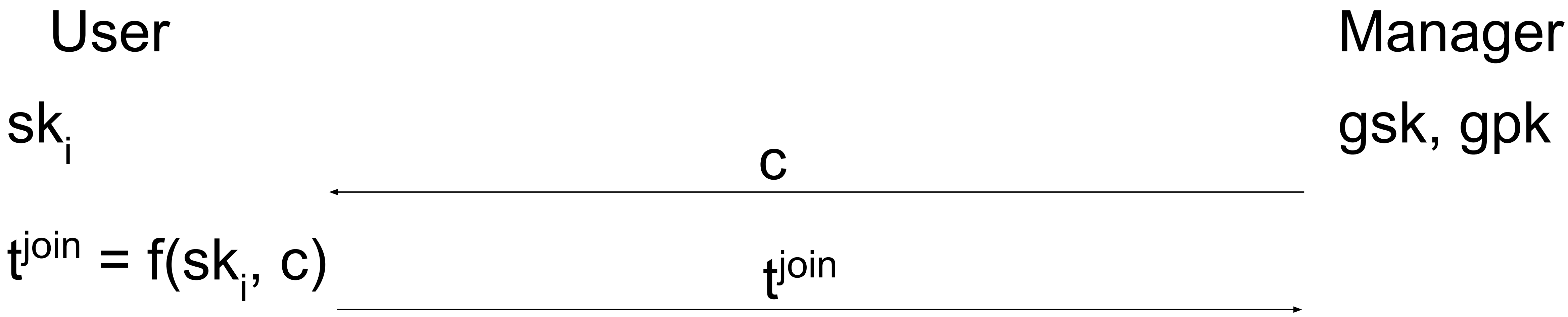
Manager

gsk, gpk

c

Post-Quantum EPID Signature

Join



User

Manager

sk_i

gsk, gpk

c

$t^{join} = f(sk_i, c)$

t^{join}

Post-Quantum EPID Signature

Join

User

Manager

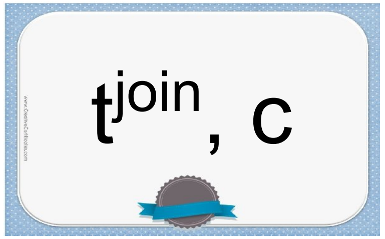
sk_i

gsk, gpk

$\xleftarrow{\quad c \quad}$

$t^{join} = f(sk_i, c)$

$\xrightarrow{\quad t^{join} \quad}$



t^{join}, c

$\longleftarrow$

Post-Quantum EPID Signature

Sign

$r \leftarrow \{0,1\}^\lambda$

$t = f(sk_i, r), r$

Post-Quantum EPID Signature

Sign

$r \leftarrow \{0,1\}^{\lambda}$

$t = f(sk_i, r), r$

Proof of Knowledge:

1. I know a valid certificate for t^{join}, c

Post-Quantum EPID Signature

Sign

$r \leftarrow \{0,1\}^\lambda$

$t = f(sk_i, r), r$

Proof of Knowledge:

1. I know a valid certificate for t^{join}, c
2. I know sk_i such that $t = f(sk_i, r)$ and $t^{join} = f(sk_i, c)$

Post-Quantum EPID Signature

Sign

$r \leftarrow \{0,1\}^\lambda$

$t = f(sk_i, r), r$

Proof of Knowledge:

1. I know a valid certificate for t^{join}, c
2. I know sk_i such that $t = f(sk_i, r)$ and $t^{join} = f(sk_i, c)$
3. There is no signature in SIG-RL such that $f(sk_i, r')=t'$

publish proof and t as signature

Instantiation

Need	Choices
Zero Knowledge PoK	ZKB++, Ligero, zk-STARK
PRF/CRHF	
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Post-quantum EPID signature size (group size 2^{30}):

Instantiation

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PRF/CRHF	AES, MiMC, **LowMC**
Post-Quantum Signature from symmetric primitives	**Tree-based**, **SPHINCS**, Fish

Post-quantum EPID signature size (group size 2^{30}): **217MB**

Way too big!! Culprit: signature verification inside PoK

Post-Quantum EPID Signature

Requires signature verification!
How can we remove this?

Sign

$r \leftarrow \{0,1\}^\lambda$

$t = f(sk_i, r), r$

Proof of Knowledge:

1. **I know a valid certificate for t^{join}, c**
2. I know sk_i such that $t = f(sk_i, r)$ and $t^{join} = f(sk_i, c)$
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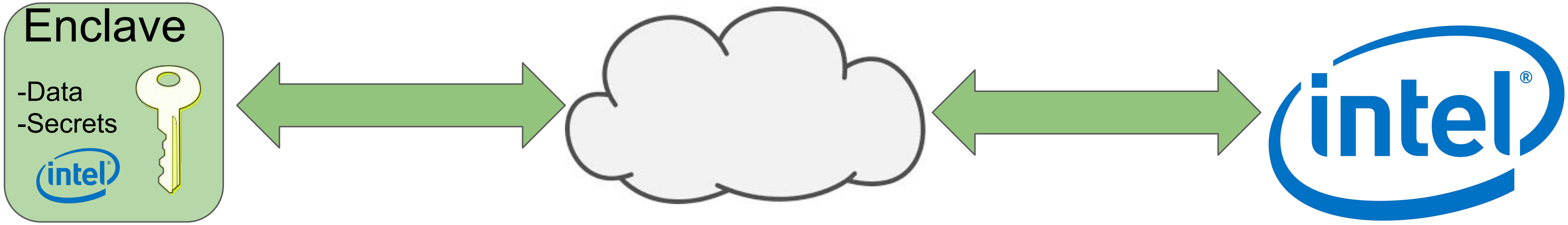
publish proof and t as signature

The Attestation Setting

Each Intel SGX attestation involves contacting Intel, who verifies the attestation for you.



How can we leverage this to reduce signature sizes?

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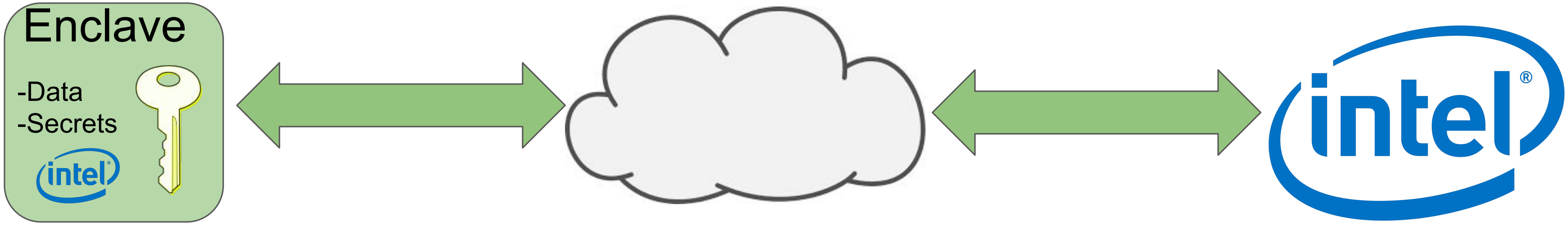

How can we leverage this to reduce signature sizes?

Idea: If group manager has to be online, maybe it can update users’ certificates

User anonymity sets relative to last certificate update

Signatures for Attestation

Manager puts user credentials in a Merkle tree and signs root

Users get newest Merkle root/inclusion proof when they connect to the manager

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Signature on Merkle tree root can be verified outside PoK

Only need much smaller Merkle inclusion proof inside PoK

Signatures for Attestation

$r \leftarrow \{0,1\}^\lambda$

$t = f(sk_i, r), r$

Proof of Knowledge:

1. **I know an inclusion proof for t^{join}, c**
2. I know sk_i such that $t = f(sk_i, r)$ and $t^{join} = f(sk_i, c)$
3. There is no signature in SIG-RL such that $f(sk_i, r')=t'$

publish proof, t, **and signed Merkle root** as signature

Similar to post-quantum Ring signatures of Derler et al [DRS17]

Signature Sizes

Group Size	RO Model*	QRO Model*
2^{7}	1.37MB	2.64MB
2^{10}	1.85MB	3.59MB
2^{20}	3.45MB	6.74MB
2^{30}	5.05MB	9.89MB
2^{40}	6.65MB	13.0MB

Potential application: large data transfer, e.g. streaming movies

*under ideal cipher assumption on LowMC