How to Hide MetaData in MLS-Like Secure Group Messaging: Simple, Modular, and Post-Quantum

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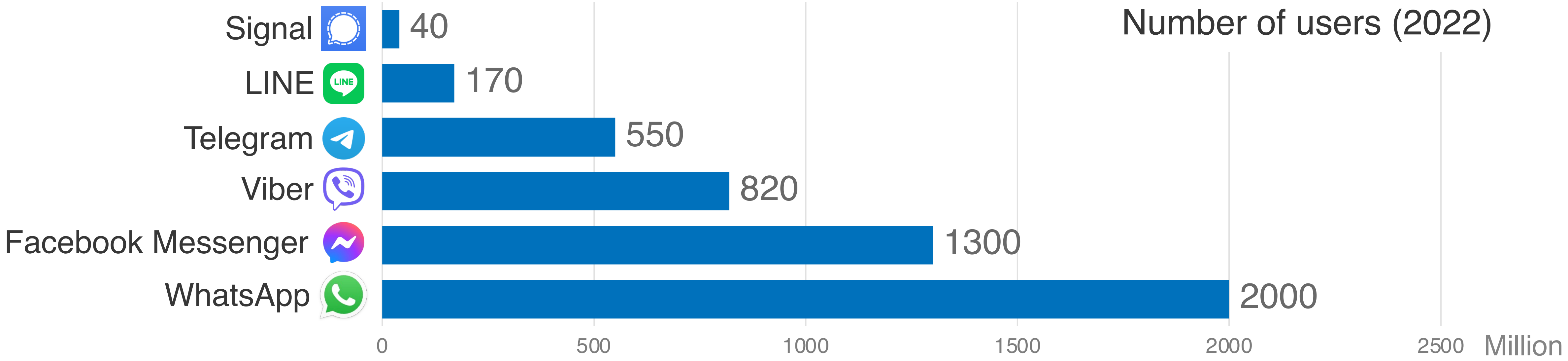
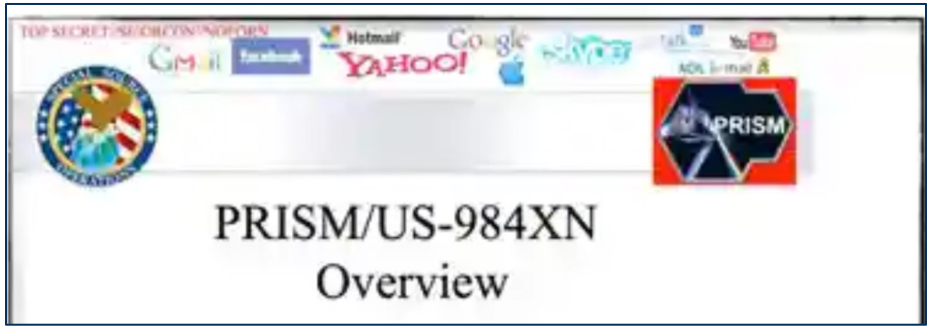
Secure group messaging (SGM)

SGM apps are used in worldwide

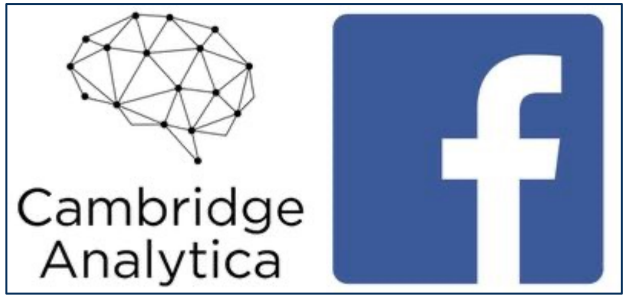


Ref: https://www.businessofapps.com/data/messaging-app-market/

Widespread data collection by governments and corporations



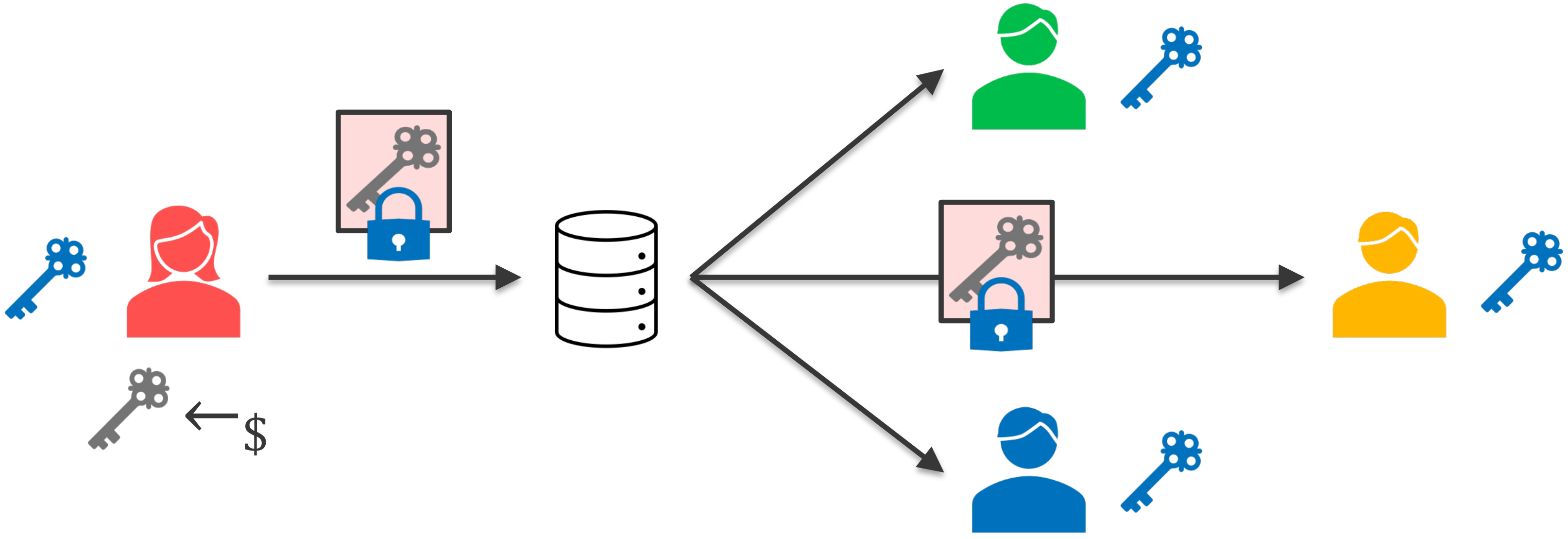
PRISM/US-984XN
Overview



Continuous Group Key Agreement (CGKA) [C:ACDT20]

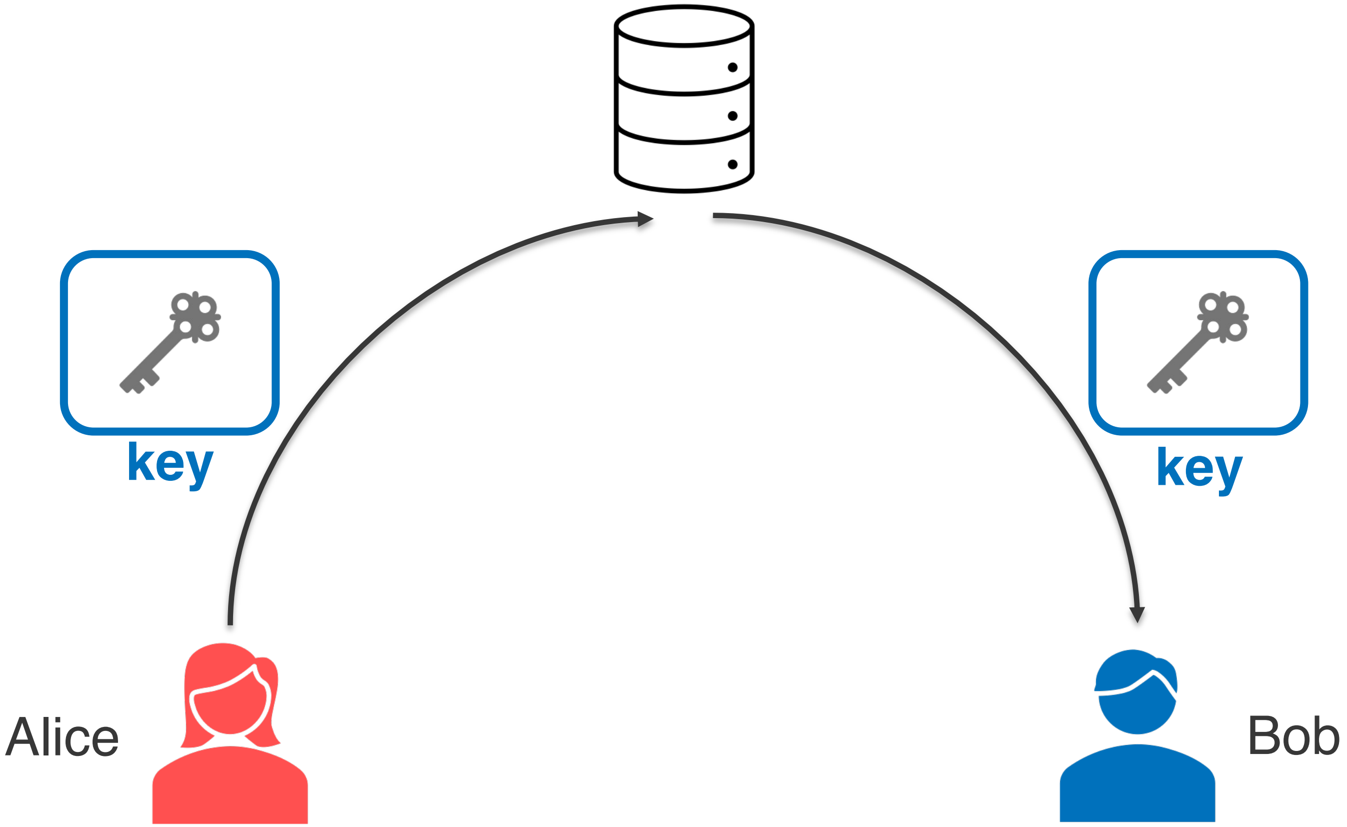
Capture the core functionality underlying SGM
e.g., TreeKEM [BBM+22,CCS:AHKM22,EC:AAC+22,…] and Chained CmPKE [CCS:**HK**P**P**W21]

- Add/Remove a party
- Update own key materials (e.g., PKE/signature keys)
- **Update group secret key** (Ratcheting)



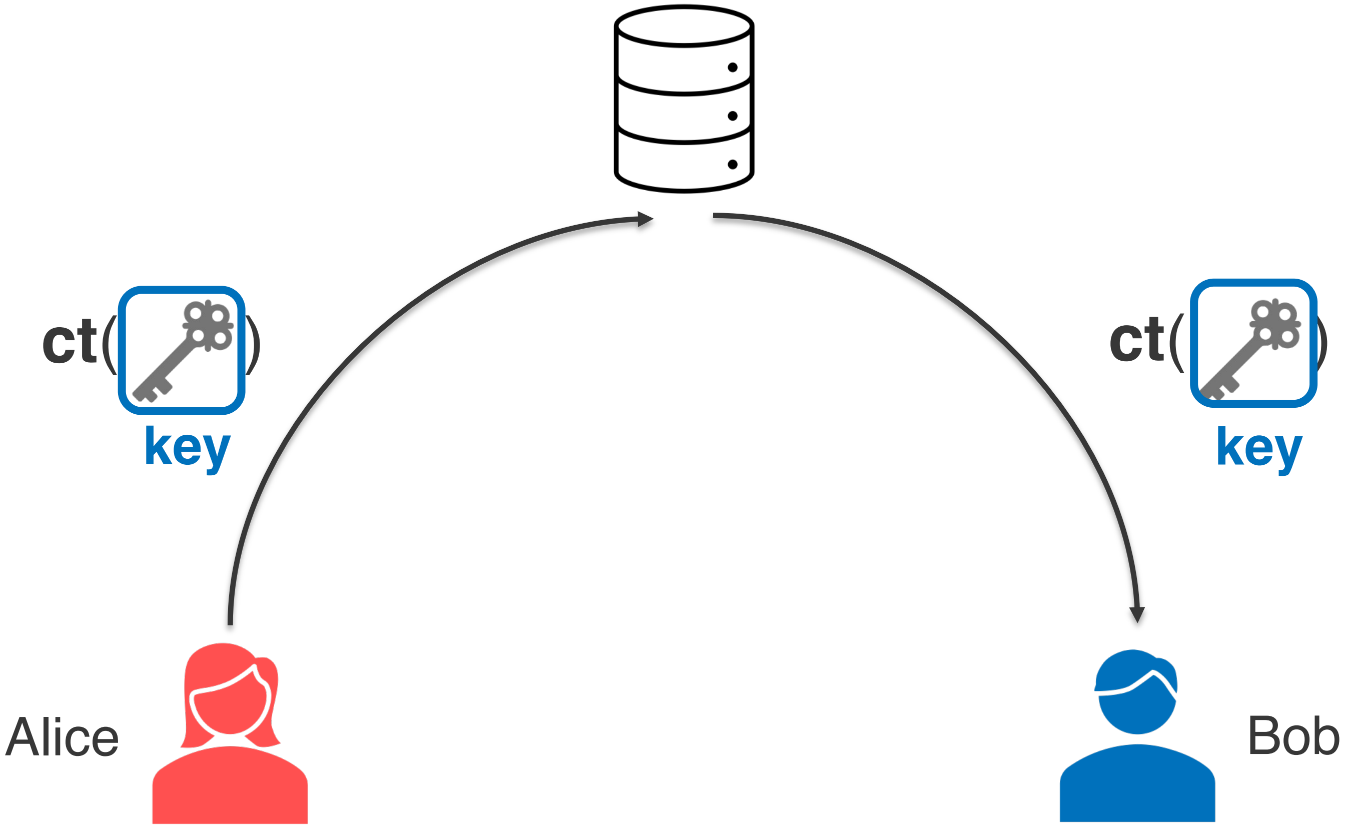
How CGKA work

- The goal is to share **secret key** among group members
  - Users communicate asynchronously through the server



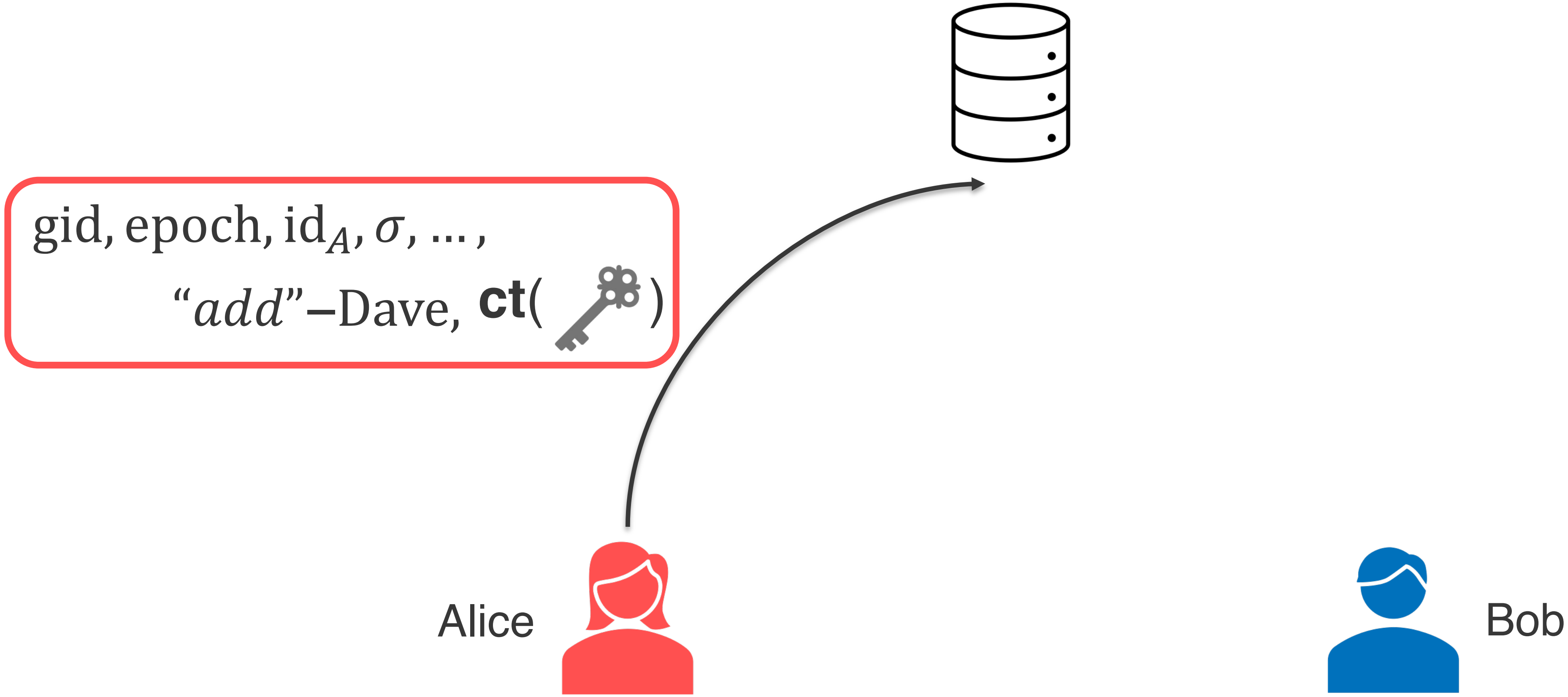
How CGKA work

- The goal is to share **<u>secret key</u>** among group members
  - Users communicate asynchronously through the server
- The secret key is protected by encryption



How CGKA work

- For delivery, the group identity and epoch are attached
- The sender’s id or the new member’s id may be included



$\mathrm{gid}, \mathrm{epoch}, \mathrm{id}_A, \sigma, \ldots,$

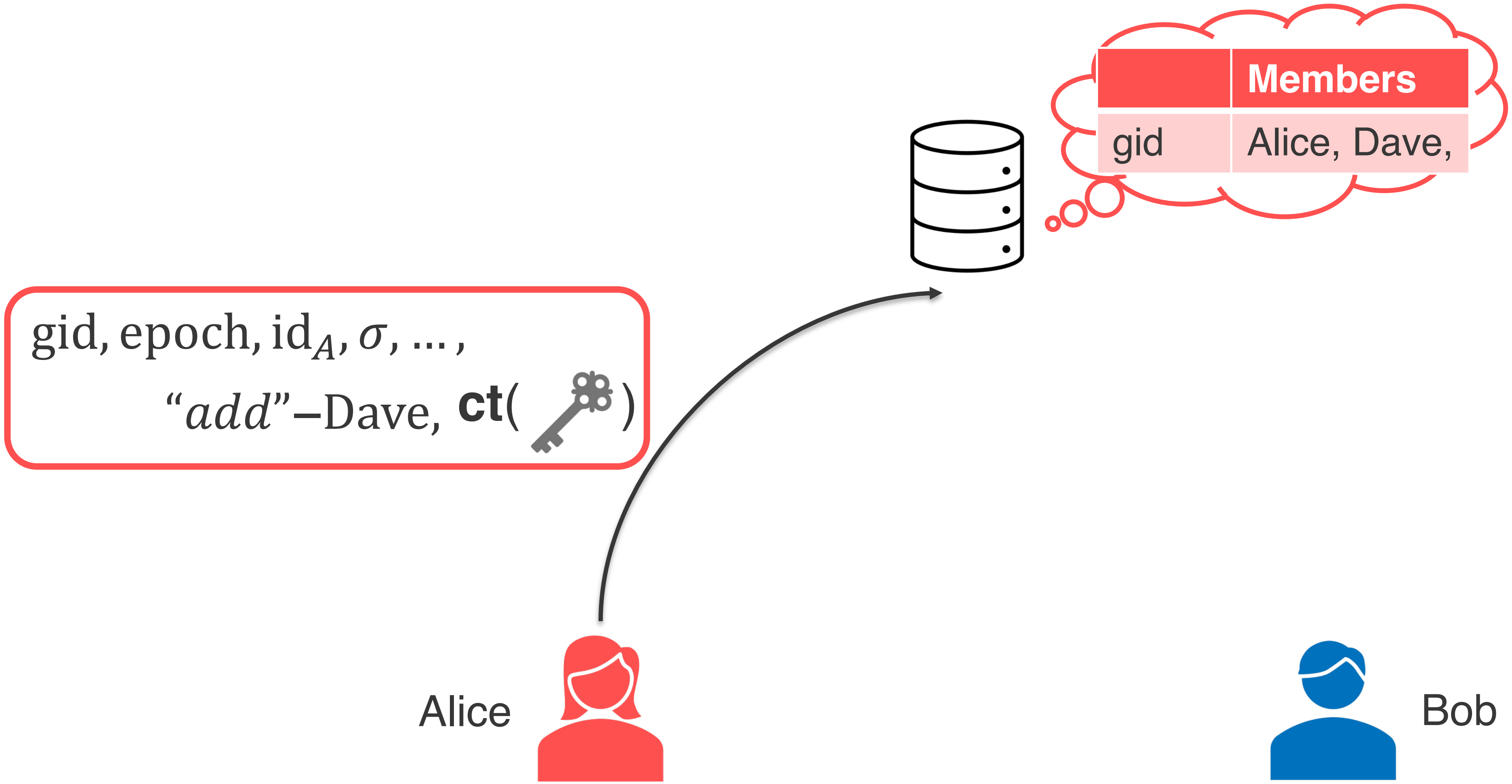
$\text{“}add\text{”–Dave},$ **ct**(🔑)

Alice

Bob

How CGKA work

- Sever explicitly obtains users’ info. from exchanged contents



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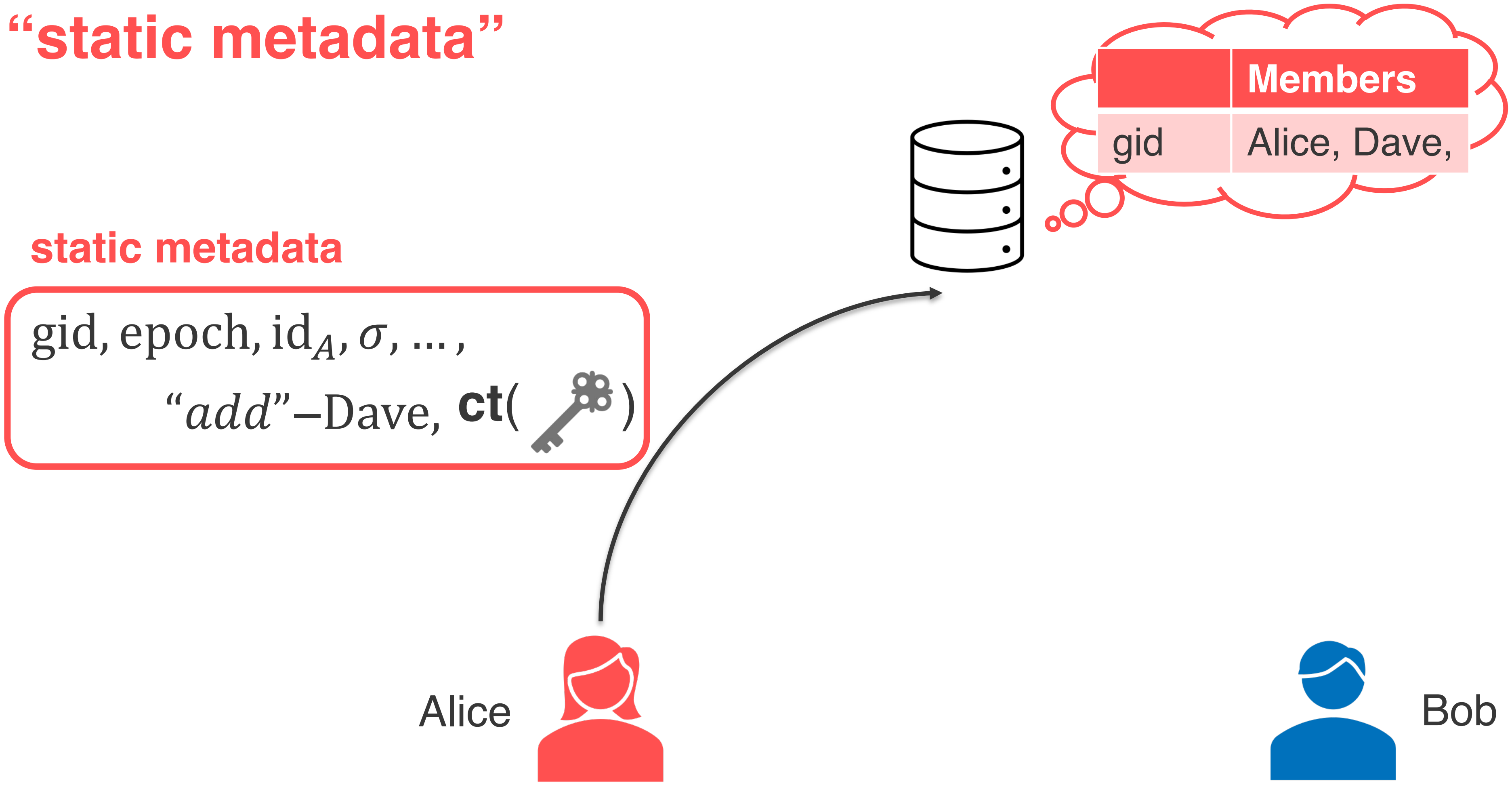
“add”–Dave, **ct**(🔑)

	Members
gid	Alice, Dave,

How CGKA work

- Sever explicitly obtains users’ info. from exchanged contents

Call them “static metadata”



static metadata

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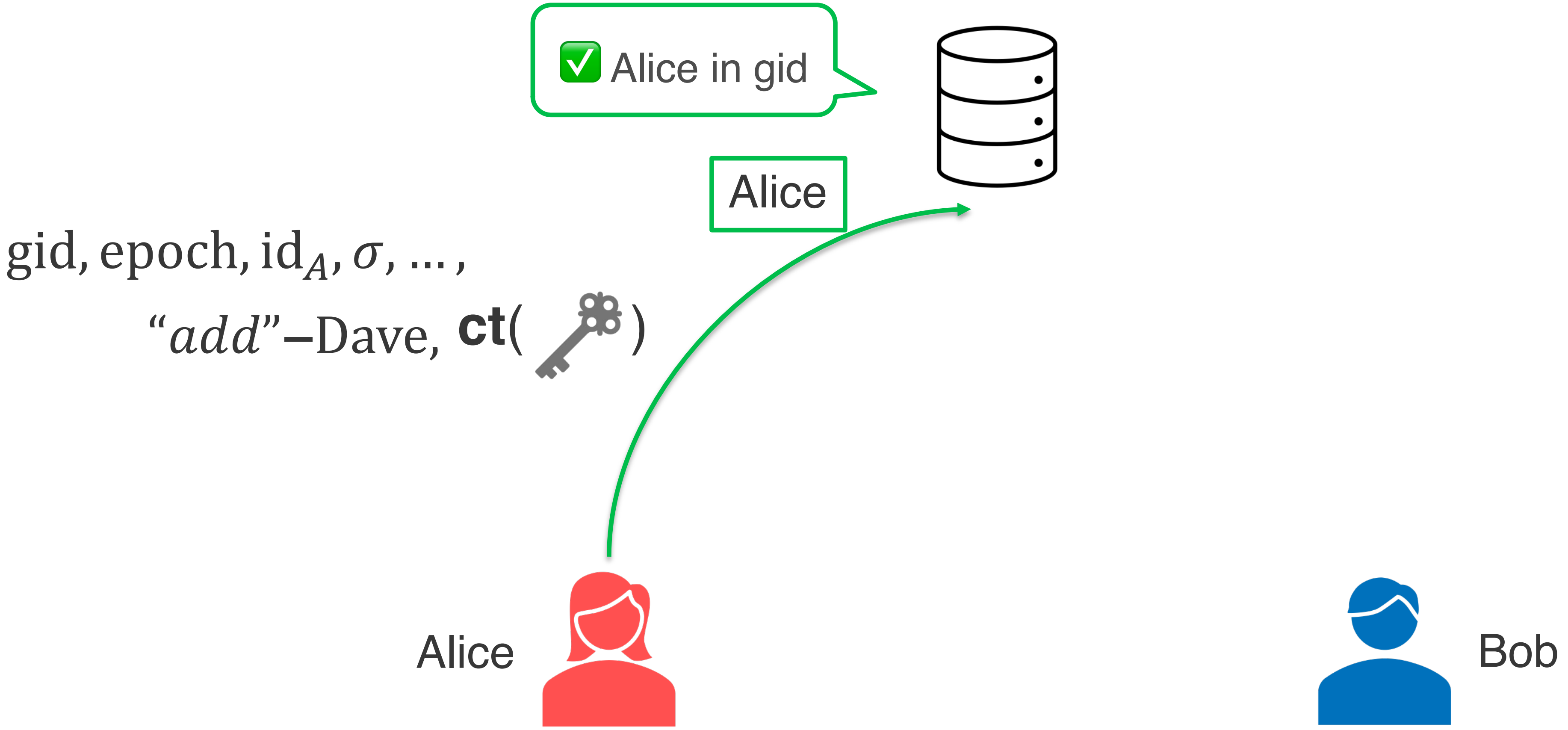
How CGKA work

- Server authenticates users with e.g., password or certificates



✅ Alice in gid

Alice

$\mathrm{gid}, \mathrm{epoch}, \mathrm{id}_A, \sigma, \ldots,$

“add”–Dave, **ct**(🔑)

Alice

Bob

How CGKA work

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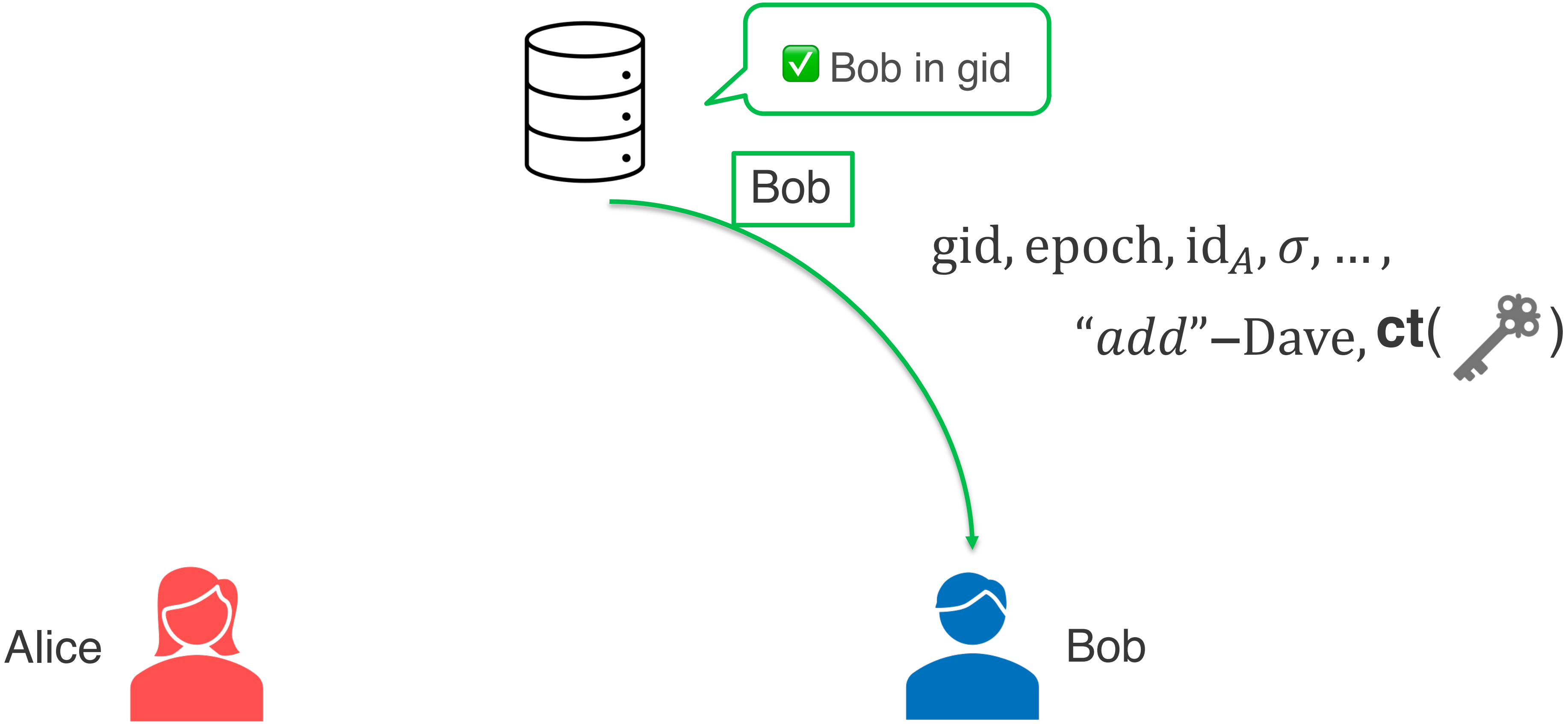

✅ Bob in gid

Bob

$\text{gid}, \text{epoch}, \text{id}_A, \sigma, \ldots,$

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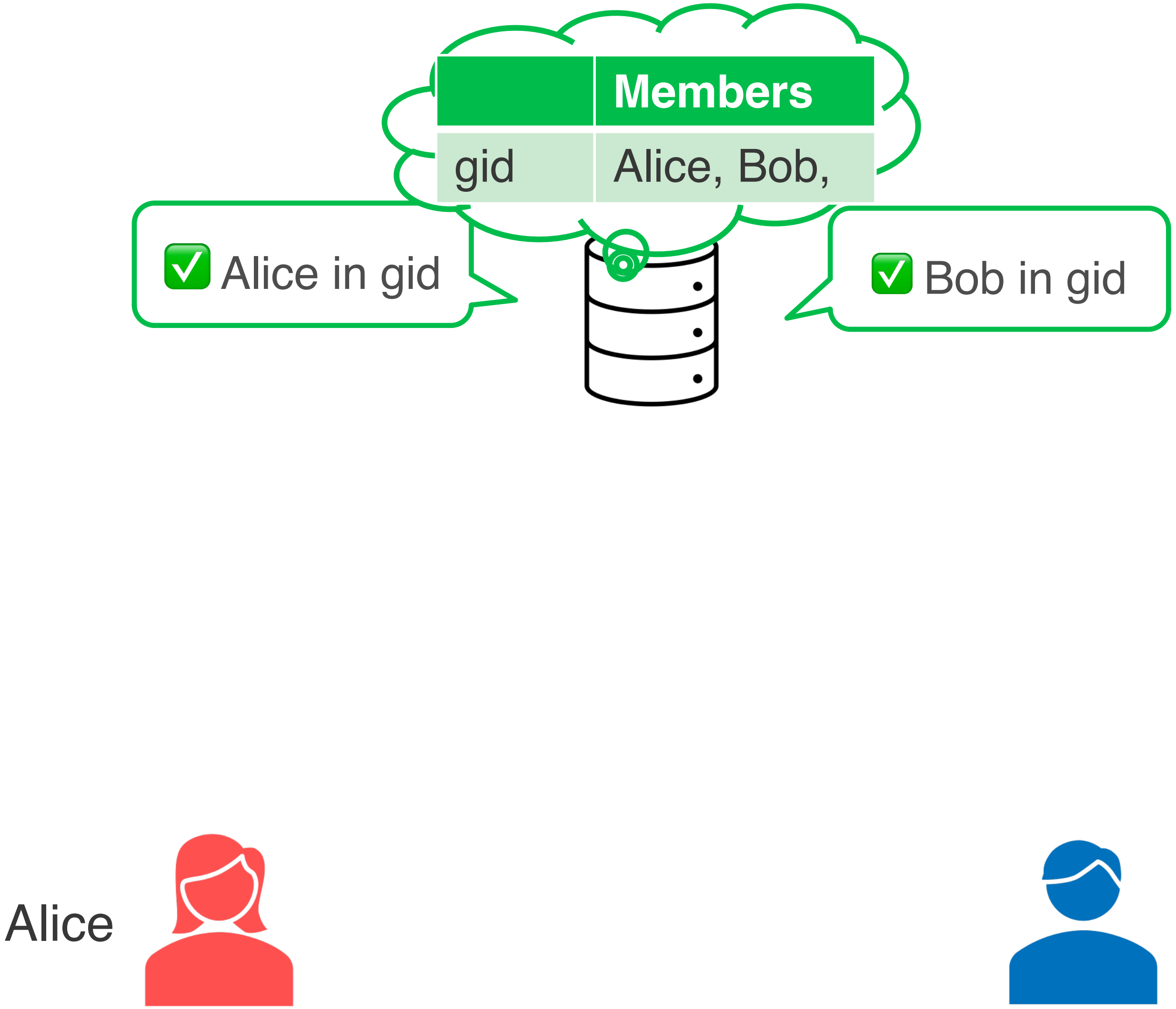
Alice

Bob

How CGKA work

- Server implicitly obtains users' information from access patterns



	Members
gid	Alice, Bob,

How CGKA work

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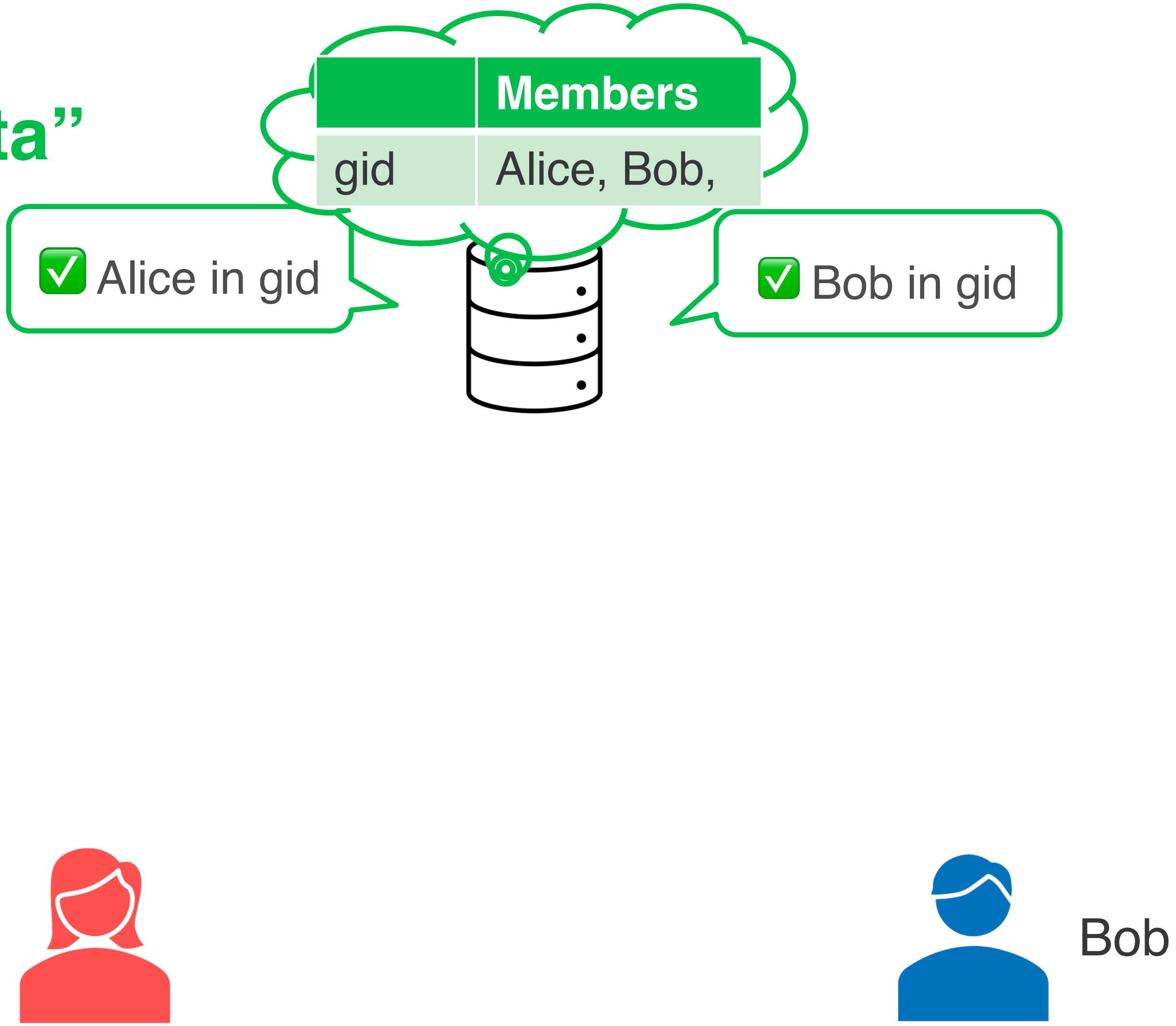
Call them "dynamic metadata"



	Members
gid	Alice, Bob,

✓ Alice in gid

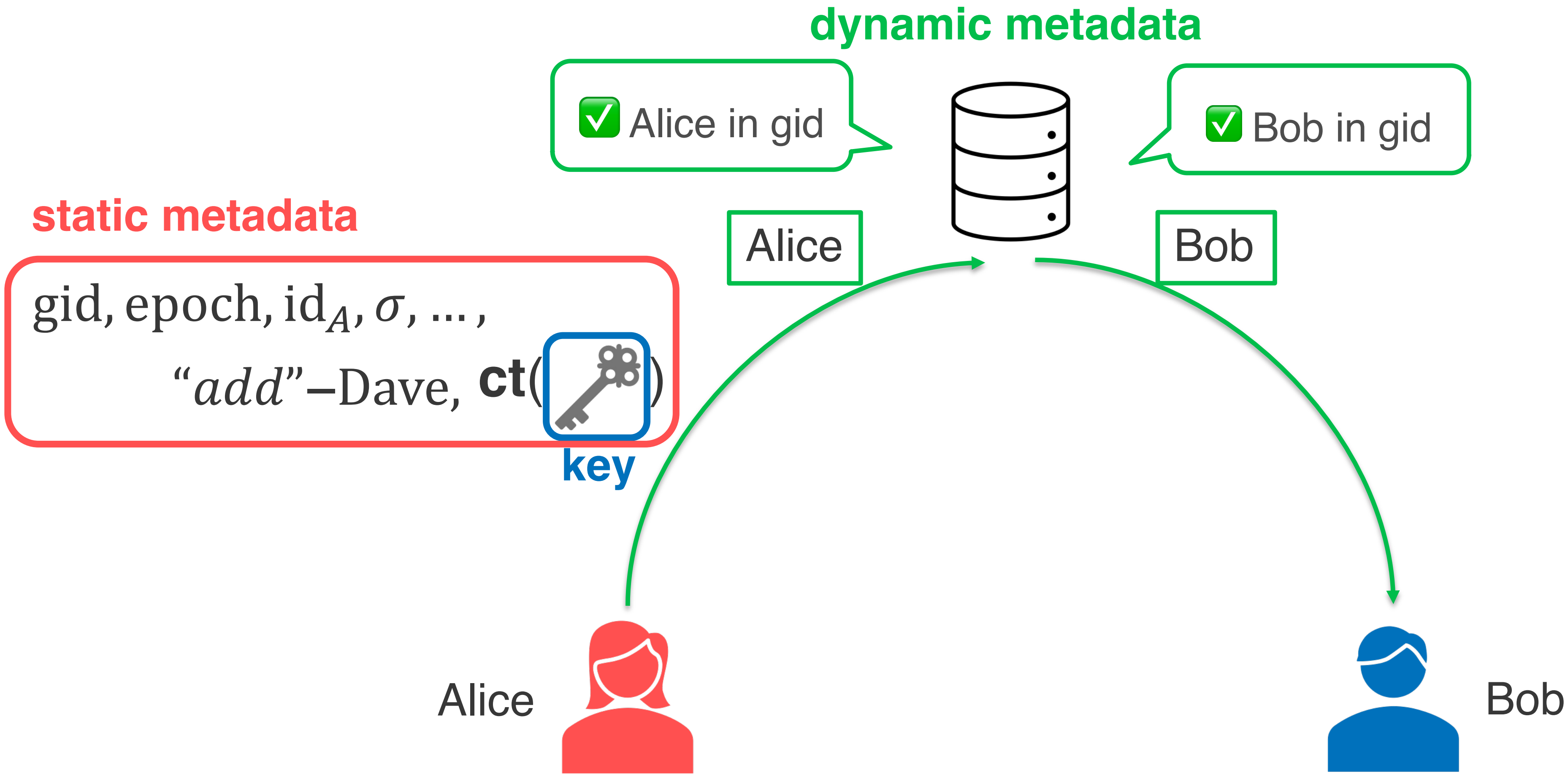
✓ Bob in gid

Alice

Bob

Summary of sensitive information in CGKA

There is three types of sensitive information:
secret key, **static metadata**, and **dynamic metadata**



dynamic metadata

✅ Alice in gid

✅ Bob in gid

Alice

Bob

static metadata

$\text{gid}, \text{epoch}, \text{id}_A, \sigma, \dots,$

$\text{“}add\text{”}\text{–Dave},$ **ct(**🔑**)**

key

Existing SGMs and protection of each data

	Secret keys	Secret keys +static metadata	Secret keys +static metadata +dynamic metadata
Signal	Vanilla Signal		Private Groups [SigPG]
Security proofs			
MLS	MLSPlaintext	MLSCiphertext	
Security proofs			

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No consideration!

Our contributions

	Secret keys	Secret keys +static metadata	Secret keys +static metadata +dynamic metadata
Signal	Vanilla Signal		Private Groups [SigPG]
Security proofs	✗		*Only metadata [CCS:CPZ20]
MLS	MLSPlaintext	MLSCiphertext	✓ **Contrib. 2**
Security proofs	✓ [C:ACDT20, CCS:ACDT21, C:AJM22]	✓ **Contrib. 1***	✓ **Contrib. 3**

* Prove a variant of Chained CmPKE [HKPPW21]

Contribution 1: Formal analysis of static metadata

Propose a UC security model $\mathcal{F}_{CGKA}^{ctxt}$
capturing the security of key and static metadata

- Extend the state-of-the-art model [C:AJM22,CCS:HKPPW21]
  - Considers active adversaries and malicious insiders
  - Support selective downloading of contents

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MLS	MLSPlaintext	MLSCiphertext	**Contrib. 2**
Security proofs	[C:ACDT20, CCS:ACDT21, C:AJM22]	**Contrib. 1**	**Contrib. 3**

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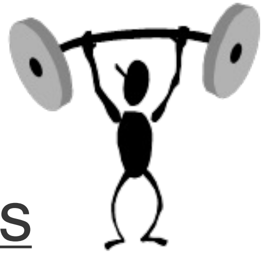
- Extend the state-of-the-art model [C:AJM22,CCS:HKPPW21]
  - Considers active adversaries and malicious insiders
  - Support selective downloading of contents
- Propose **Chained CmPKE$^{\text{ctxt}}$** that UC-realizes $\mathcal{F}_{CGKA}^{ctxt}$
  - Based on Chained CmPKE [CCS:HKPPW21]
  - The first provably secure **static metadata-hiding CGKA**

Contribution 1: Formal analysis of static metadata

Propose a UC security model $\mathcal{F}_{CGKA}^{ctxt}$
capturing the security of key and static metadata

- Model is parameterized by leaked metadata
  - Applicable to security analysis of other CGKAs

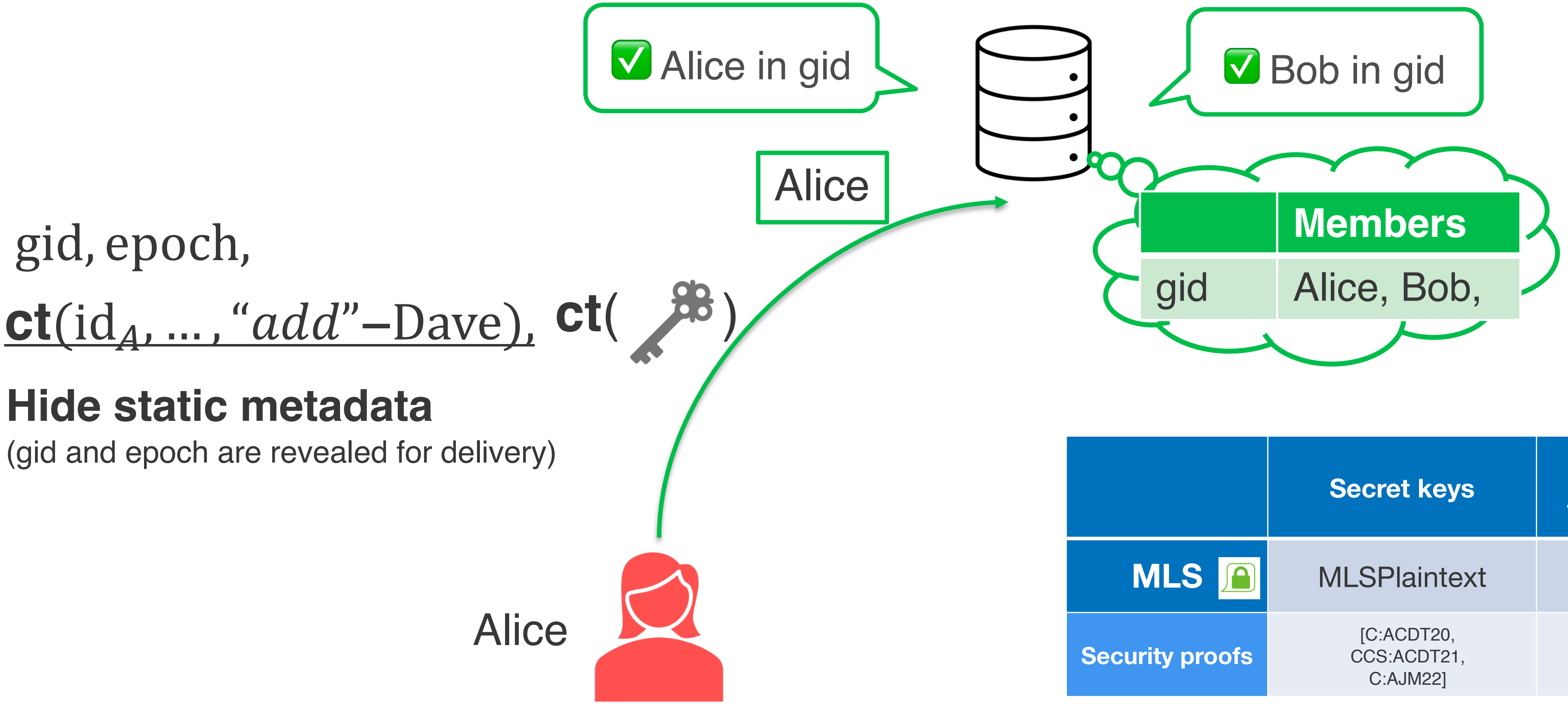


+ We analyze leaked metadata of existing CGKAs,
e.g., TreeKEM [C:AJM22], SAIK* [CCS:AHKM22], CoCoA* [EC:AAC+22]

* We analyzed the initial ePrint version.

Contribution 2: Protecting dynamic metadata

- Sevrer obtains personal information from <u>only access patterns</u>
  - Protecting static metadata alone is insufficient



gid, epoch,

$\underline{\mathbf{ct}(\mathrm{id}_A, \ldots, \text{“}add\text{”}–\mathrm{Dave})}$, **ct**(🔑)

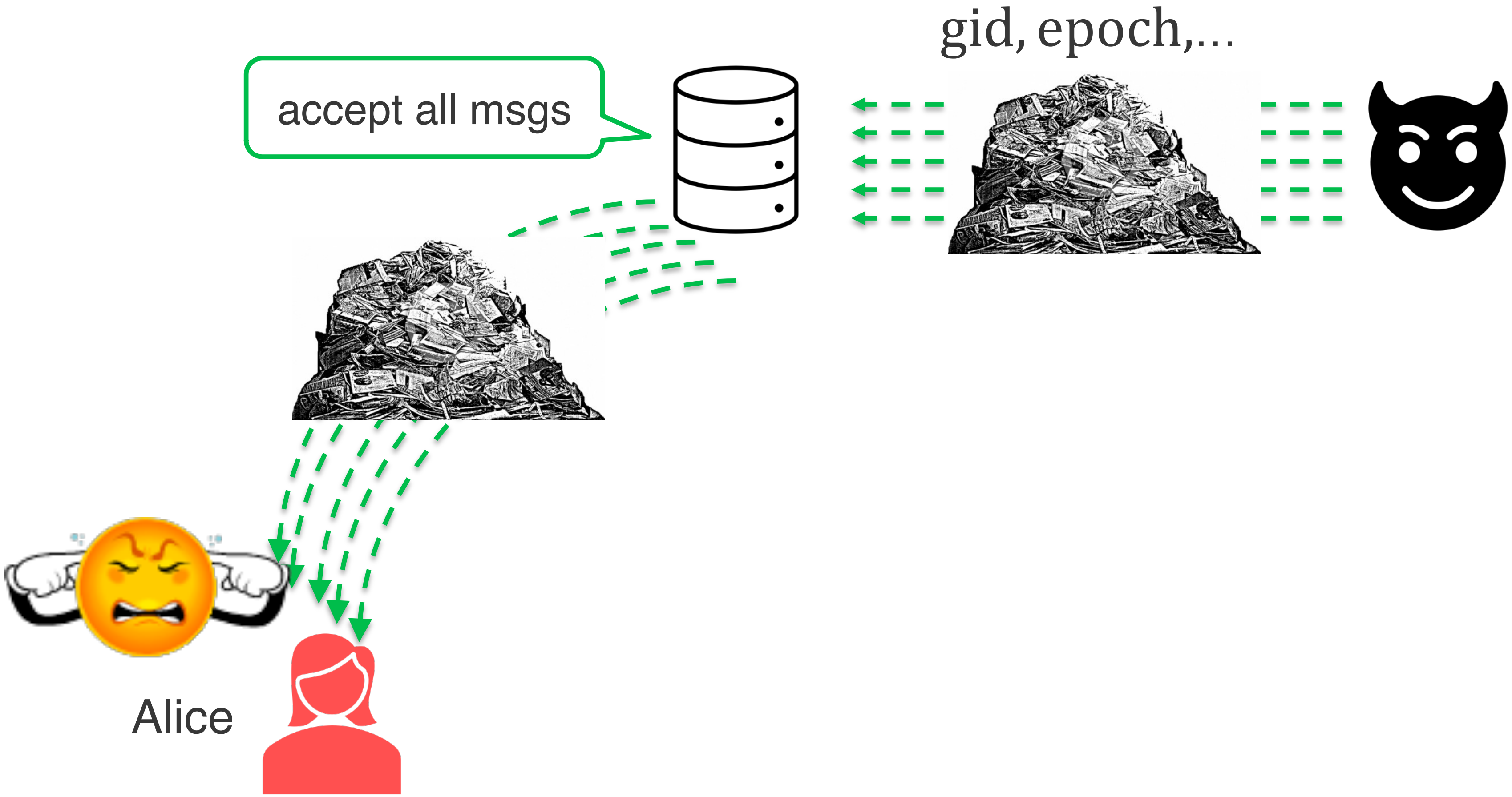
Hide static metadata

(gid and epoch are revealed for delivery)

	Secret keys	Secret keys +static metadata	Secret keys +static metadata +dynamic metadata
MLS 🔒	MLSPlaintext	MLSCiphertext	**Contrib. 2**
Security proofs	[C:ACDT20, CCS:ACDT21, C:AJM22]	**Contrib. 1**	**Contrib. 3**

Contribution 2: Protecting dynamic metadata

- Without authentication causes denial of service attacks against groups



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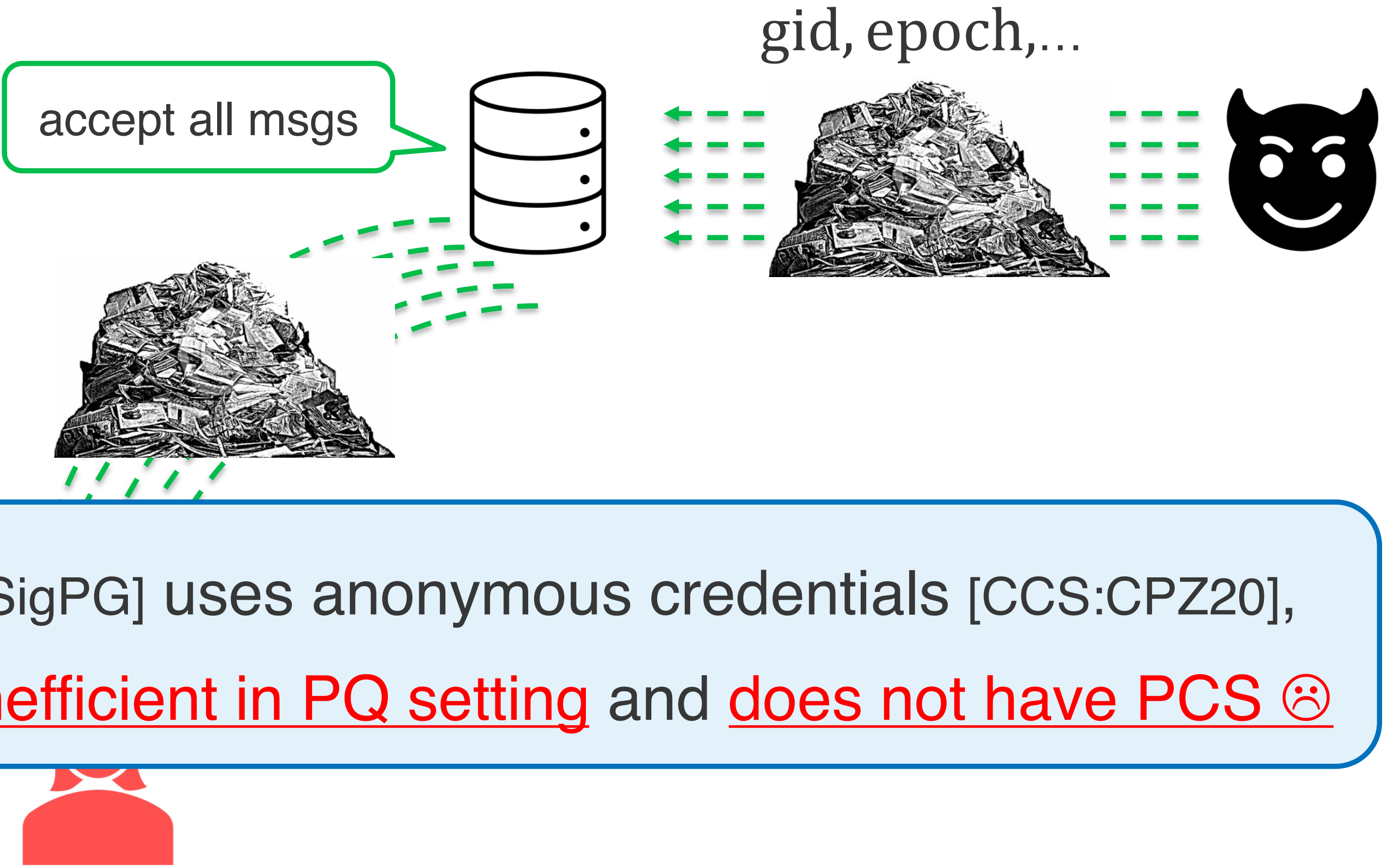
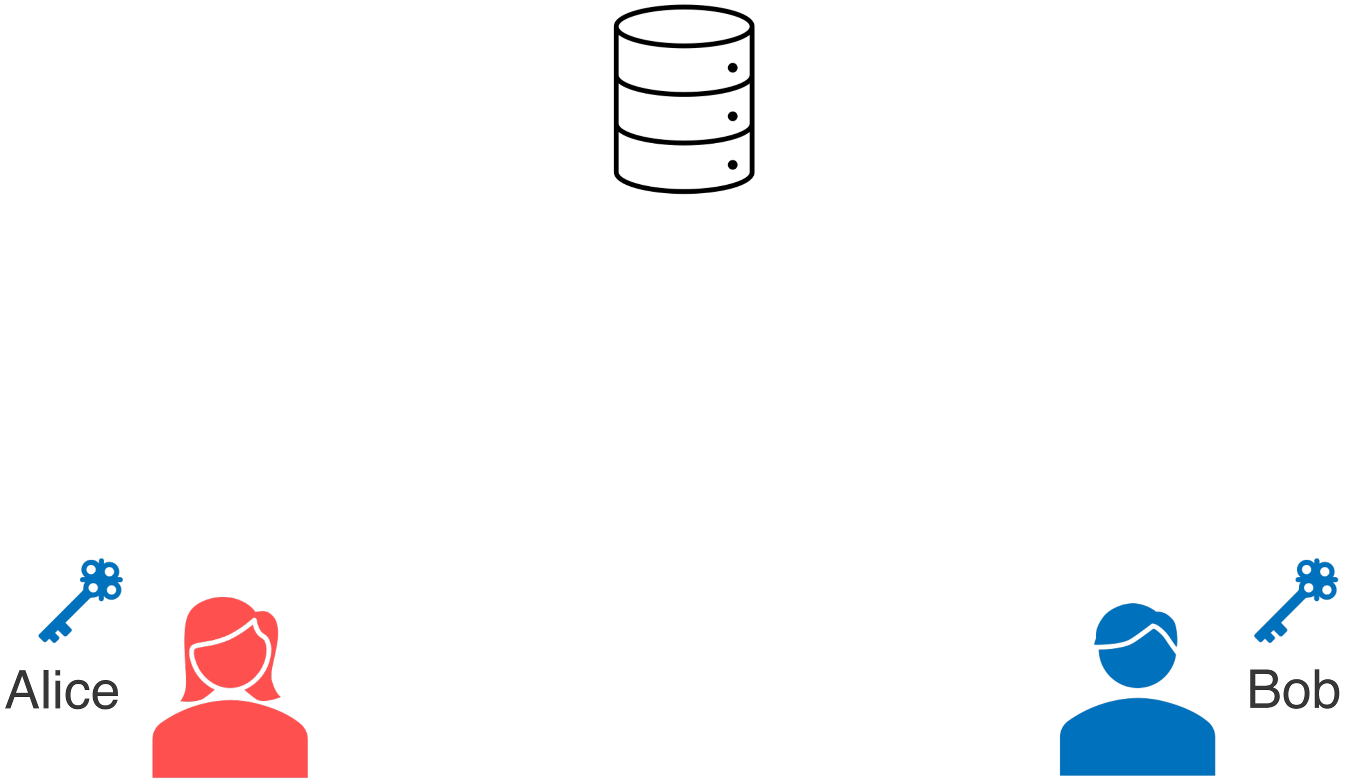


Signal [SigPG] uses anonymous credentials [CCS:CPZ20],

but it is inefficient in PQ setting and does not have PCS ☹

Contribution 2: Protecting dynamic metadata

💡 Use group secret key for the group membership authentication



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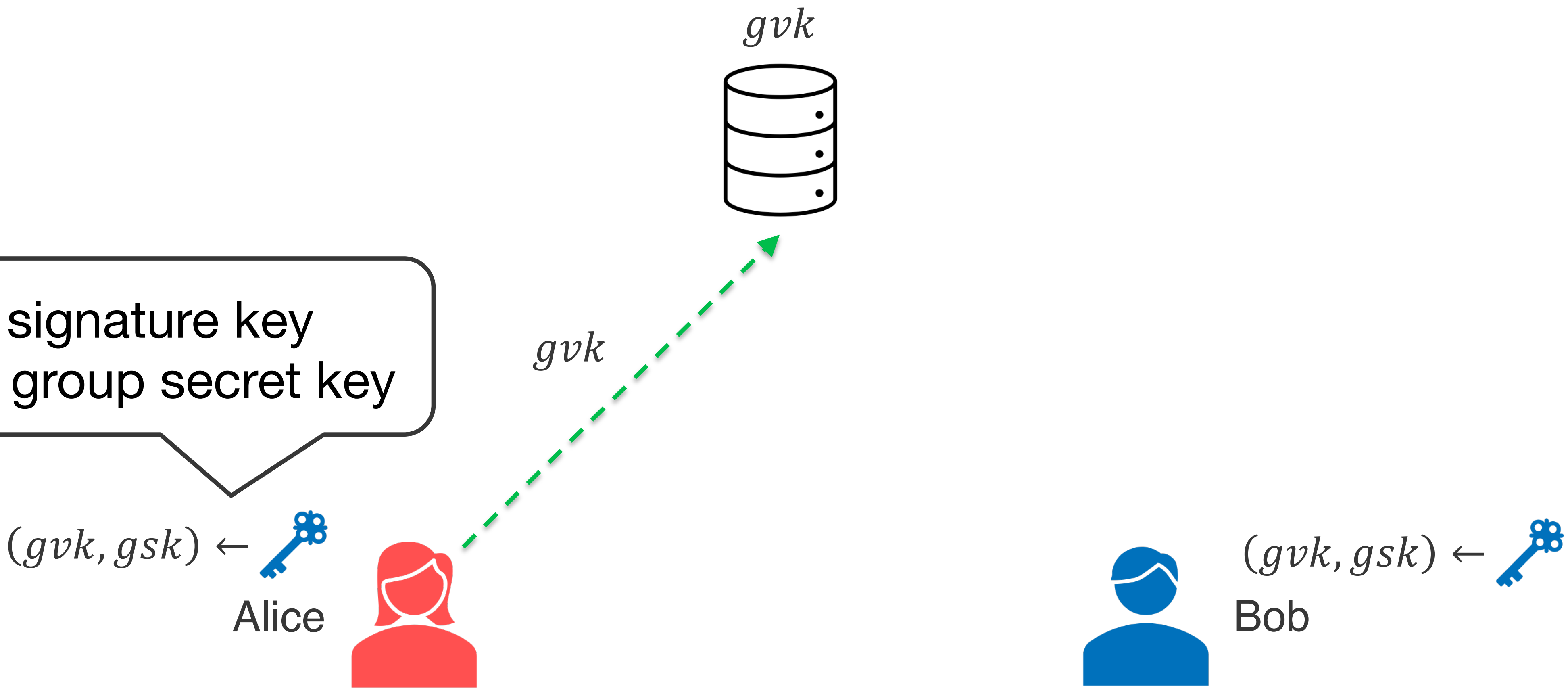
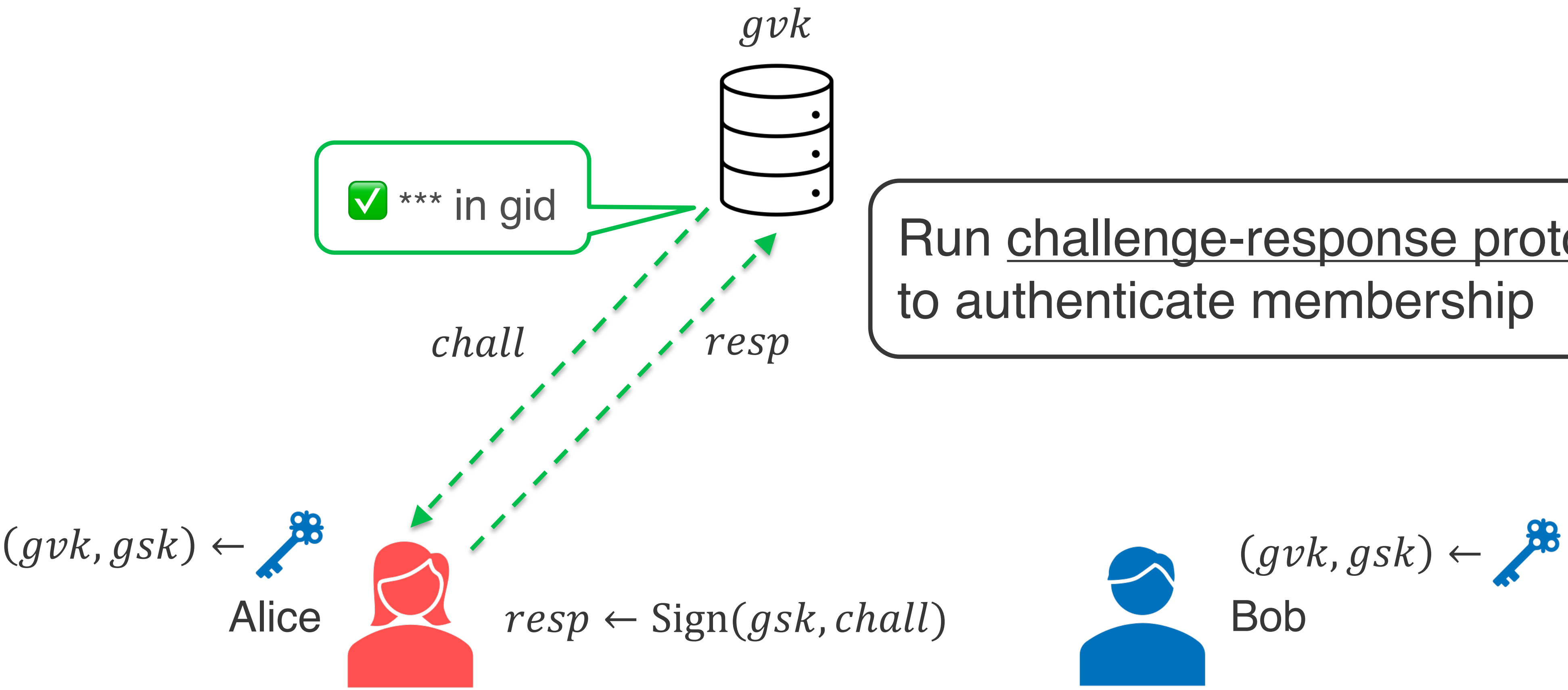


Derive a signature key from the group secret key

Contribution 2: Protecting dynamic metadata

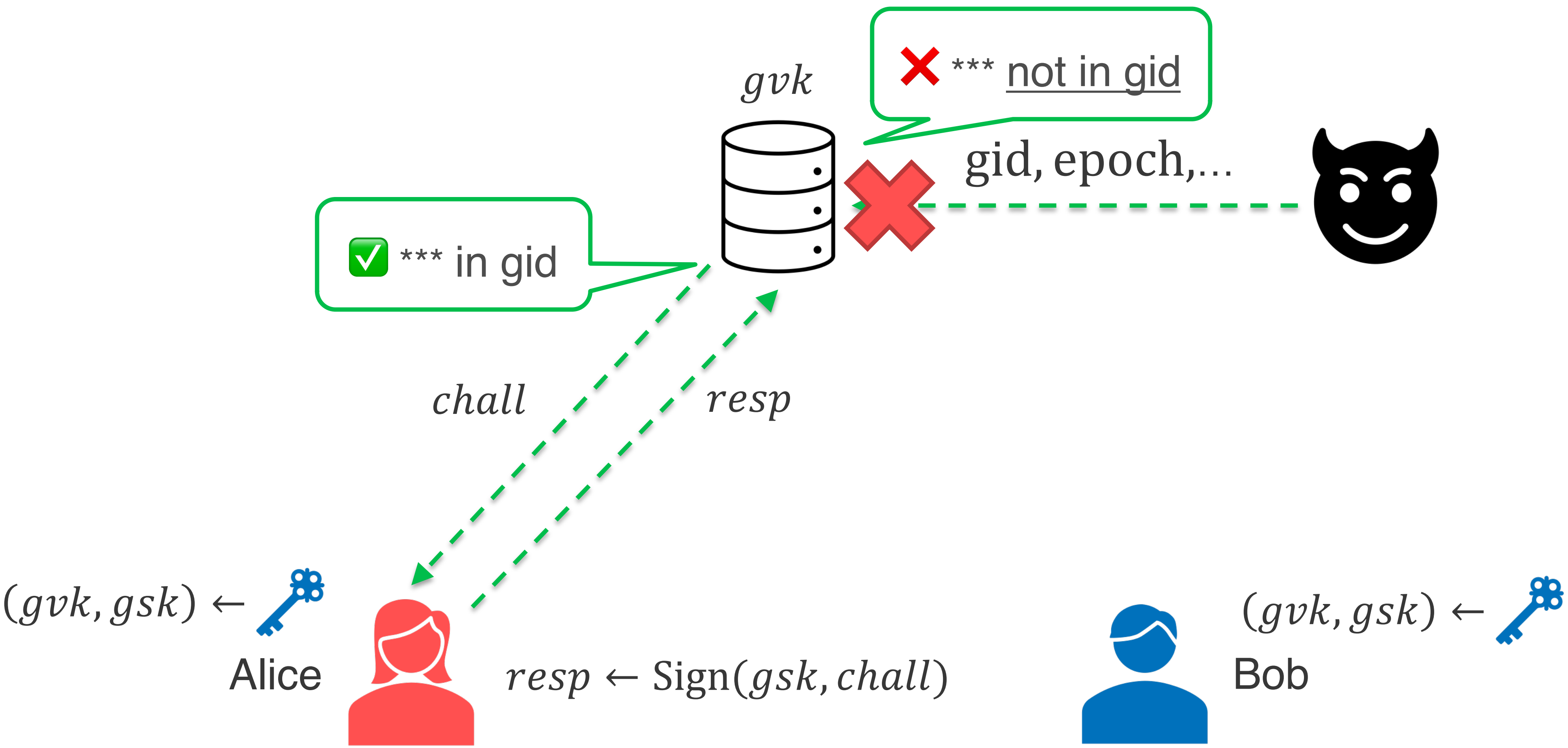
Use group secret key for the group membership authentication



Run challenge-response protocol to authenticate membership

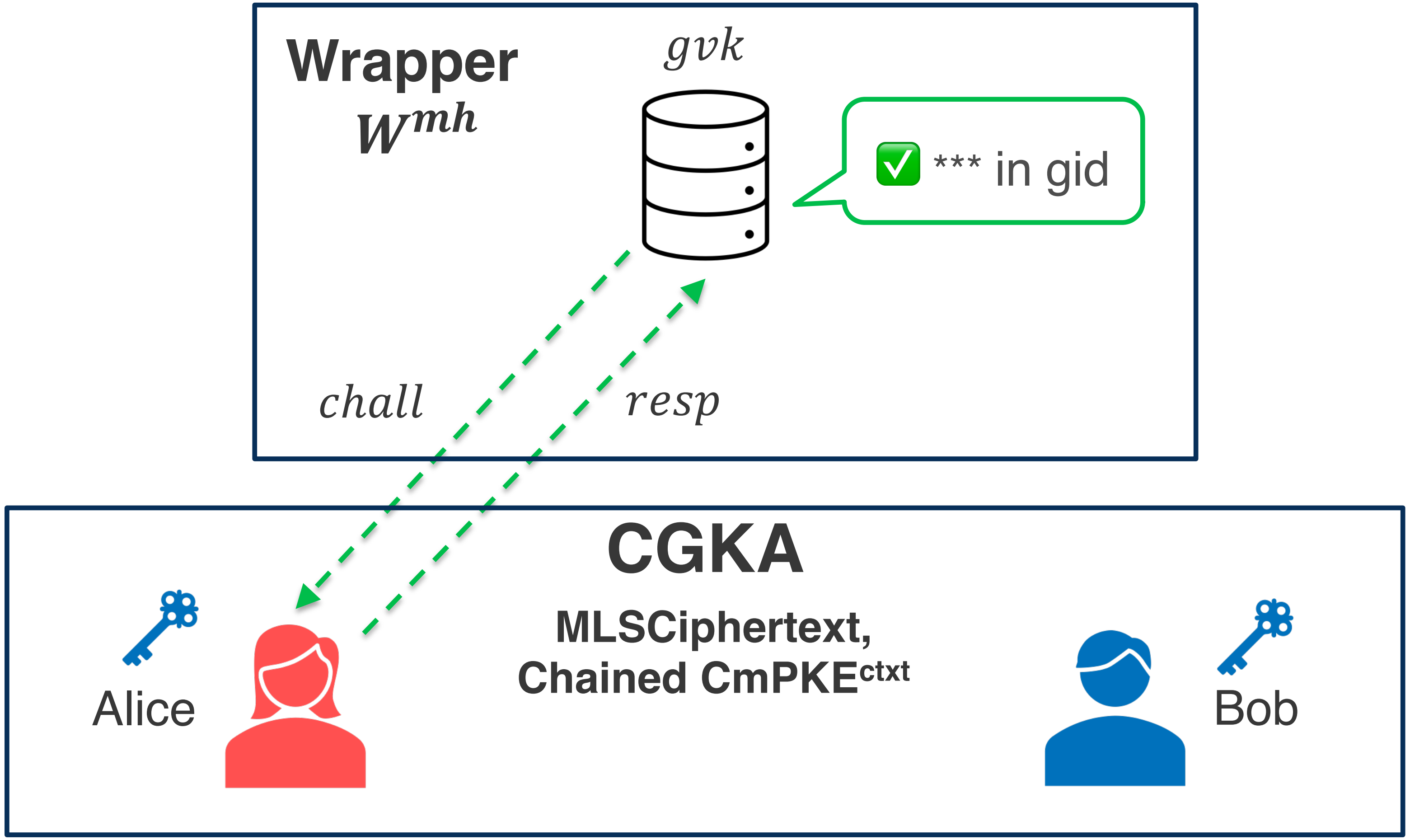
Contribution 2: Protecting dynamic metadata

Server can authenticate users without knowing other information



Contribution 2: Protecting dynamic metadata

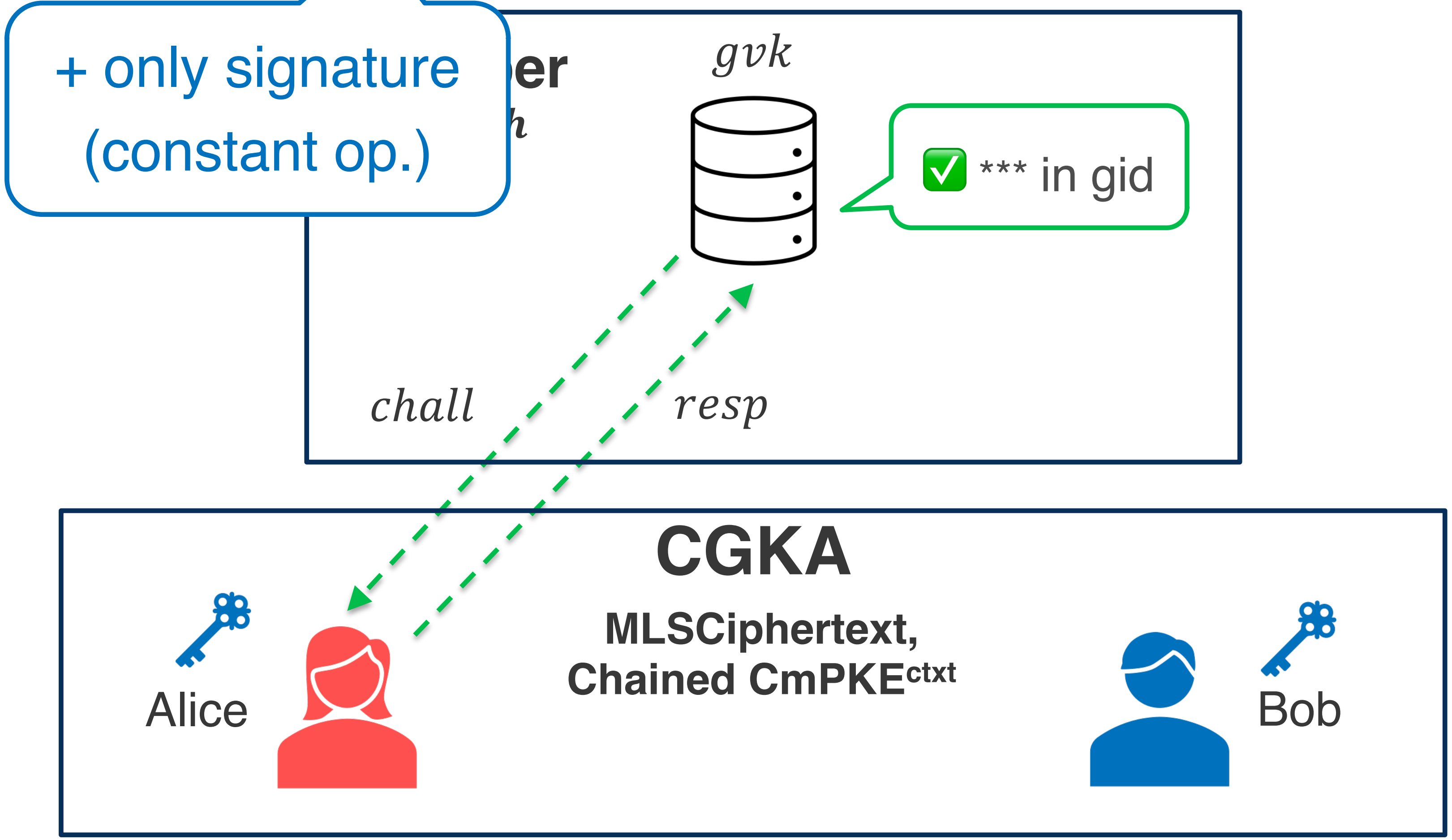
Construct an efficient and generic wrapper protocol W^{mh}



Contribution 2: Protecting dynamic metadata

Construct an efficient and generic wrapper protocol W^{mh}

+ only signature (constant op.)



MLSCiphertext, Chained CmPKE^{ctxt}

Contribution 2: Protecting dynamic metadata

Construct an efficient and generic wrapper protocol W^{mh}

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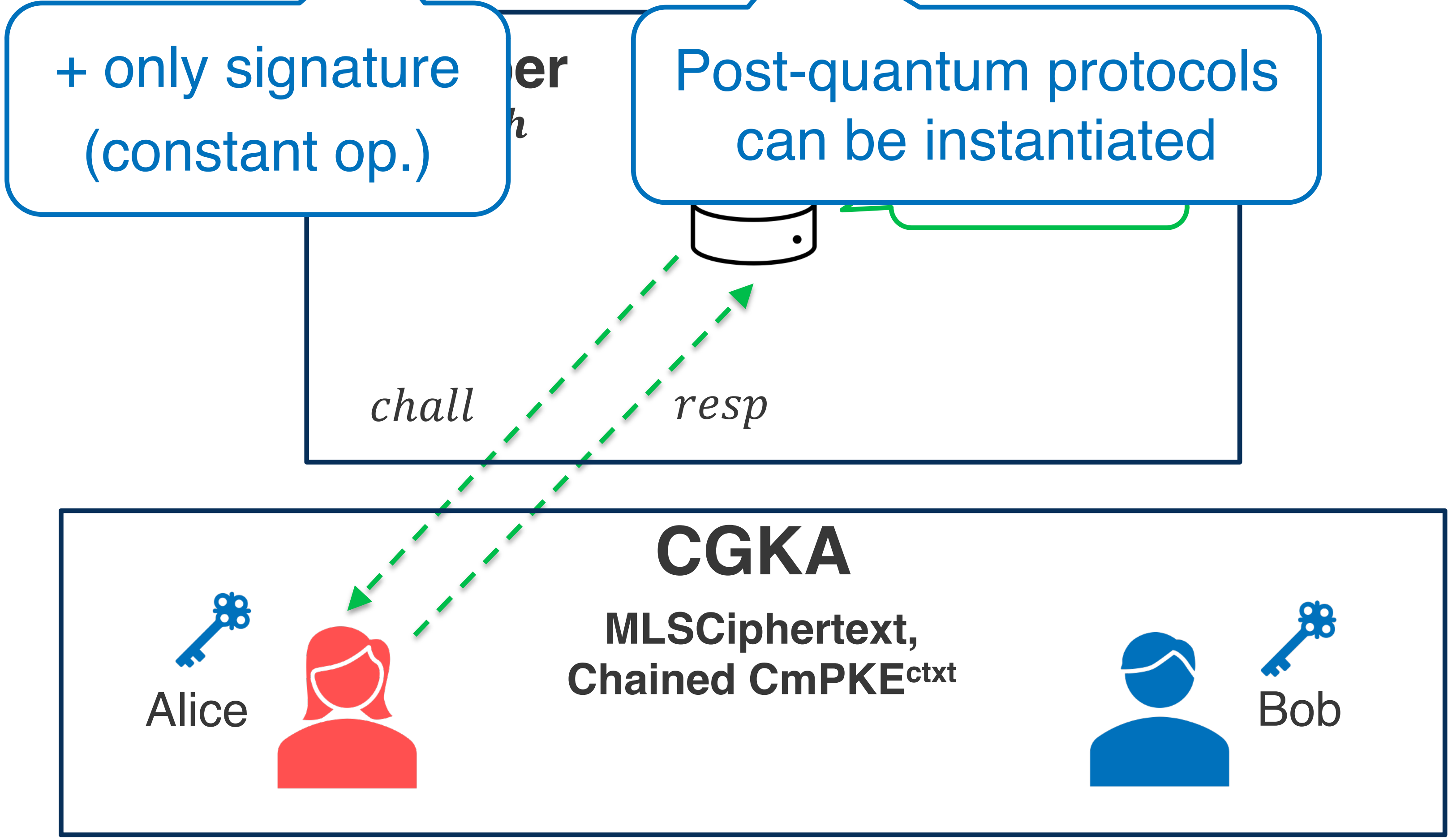
Post-quantum protocols can be instantiated



Contribution 3: Formal analysis of all metadata

Propose a UC security model $\mathcal{F}_{CGKA}^{mh}$ capturing the security of **key**, **static metadata** and **dynamic metadata**

	Secret keys	Secret keys +static metadata	Secret keys +static metadata +dynamic metadata
MLS 🔒	MLSPlaintext	MLSCiphertext	**Contrib. 2**
Security proofs	[C:ACDT20, CCS:ACDT21, C:AJM22]	**Contrib. 1**	**Contrib. 3**

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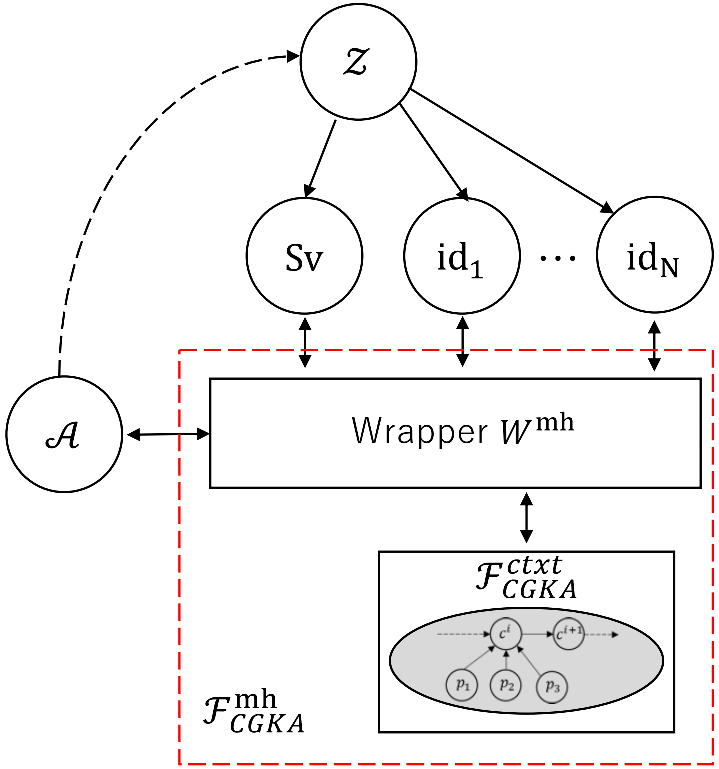
Propose a UC security model $\mathcal{F}_{CGKA}^{mh}$ capturing the security of key, static metadata and dynamic metadata

- Prove our wrapper W^{mh} realize $\mathcal{F}_{CGKA}^{mh}$ in $\mathcal{F}_{CGKA}^{ctxt}$-hybrid model



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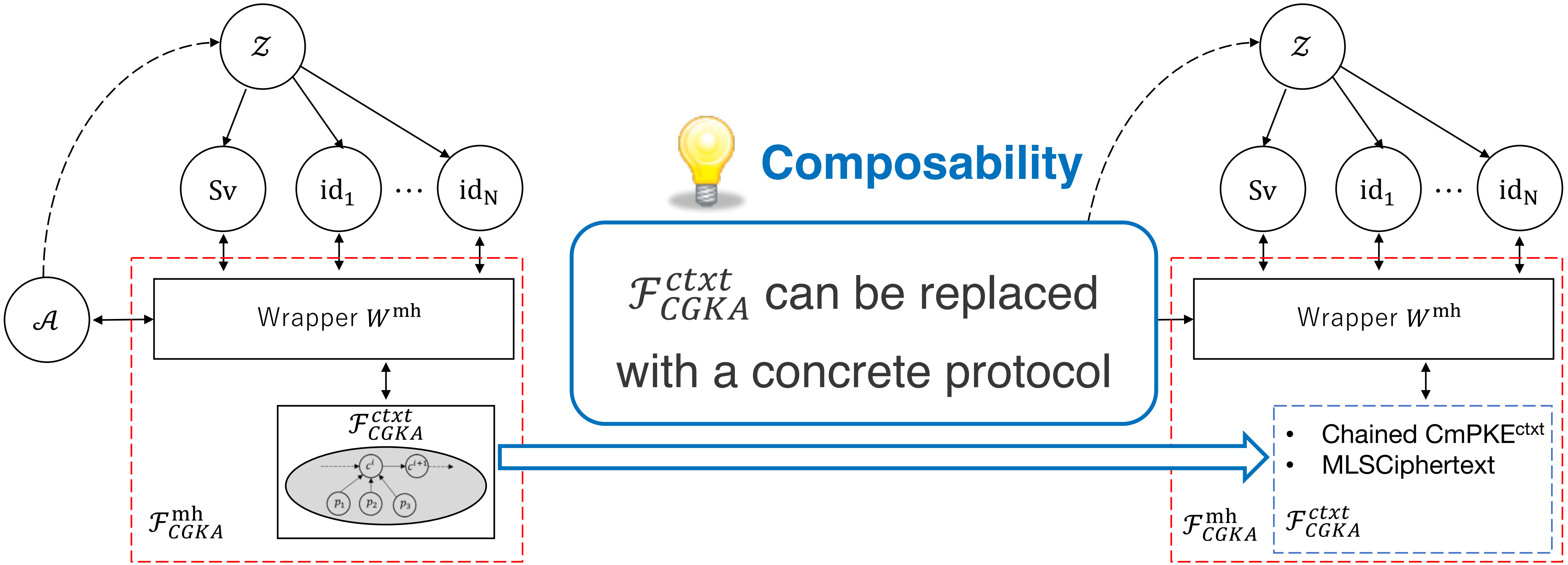
$\mathcal{Z}$
Sv
id_1
$\cdots$
id_N
$\mathcal{A}$
Wrapper W^{mh}
$\mathcal{F}_{CGKA}^{ctxt}$
c^i
c^{i+1}
p_1
p_2
p_3
$\mathcal{F}_{CGKA}^{\mathrm{mh}}$
$\mathcal{Z}$
Sv
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$\cdots$
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Wrapper W^{mh}
$\mathcal{F}_{CGKA}^{\mathrm{mh}}$
$\mathcal{F}_{CGKA}^{ctxt}$

Composability

$\mathcal{F}_{CGKA}^{ctxt}$ can be replaced with a concrete protocol

- Chained CmPKE$^{\mathrm{ctxt}}$
- MLSCiphertext

Summary

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MLS	MLSPlaintext	MLSCiphertext	✓ **Contrib. 2**
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The first probably secure metadata-hiding CGKA based on Chained CmPKE [CCS:HKPPW21]

References

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