Cryptographic Administration for Secure Group Messaging

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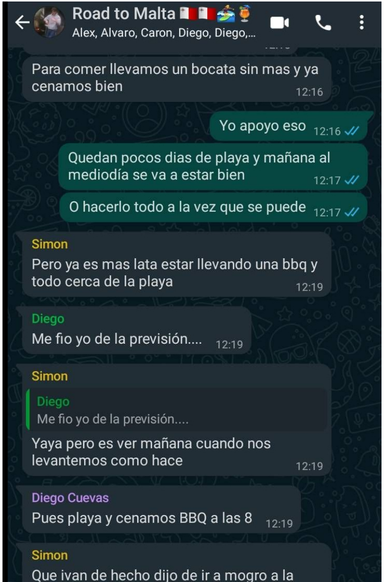
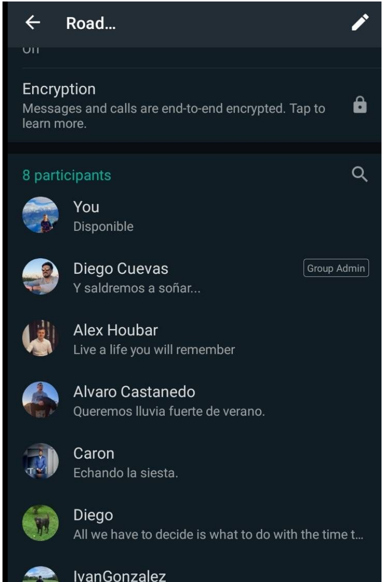
Swiss Crypto Day, 8th September 2023

(USENIX Security ’23... thank you David for your slides!)

Group Messaging?





thenewsminute.com

WhatsApp Group chats can be easily infiltrated, say researchers

Written by IANS

4–5 minutes

The WhatsApp attack on group chats takes advantage of a bug.

A team of German cryptographers has discovered flaws in WhatsApp's Group chats despite its end-to-end encryption, that makes it possible to infiltrate private group chats without admin permission.

According to a report in Wired.com, the cryptographers from Ruhr University Bochum in Germany announced this at the "Real World Crypto Security Conference in Zurich, Switzerland, on Wednesday.

"Anyone who controls the app's servers could insert new people into private group chats without needing admin permission," the report said, citing cryptographers.

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Research and teaching > Departments and schools > Information Security > News

Date **28 September 2022**

A team of cryptographers – Dan Jones and Martin Albrecht (Royal Holloway), Sofía Celi (Brave) and Benjamin Dowling (University of Sheffield) has found several, practically-exploitable cryptographic vulnerabilities in the end-to-end encryption provided by the popular Matrix protocol and its flagship client implementation Element.

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Three Lessons From Threema: Analysis of a Secure Messenger

Kenneth G. Paterson
Applied Cryptography Group, ETH Zurich

Matteo Scarlata
Applied Cryptography Group, ETH Zurich

Kien Tuong Truong
Applied Cryptography Group, ETH Zurich

Abstract

- **fine-grained perfect forward secrecy (PFS)**: compro-

Group membership?

Insecure group membership is a common design flaw in messaging.

Servers, and sometimes even users, may mount **attacks on group management**.

- Burgle into the group [RMS18]
- Censorship [BCG23]
- ...

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- The server can trivially send $(A, ..., m = \{\texttt{add}, C\})$ instead!

Group Administration?

How meaningful is security if users can't trust/control group membership?

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Can we build an efficient solution for users to *administrate* groups securely?

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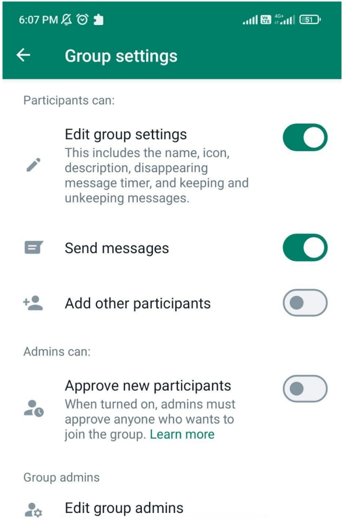
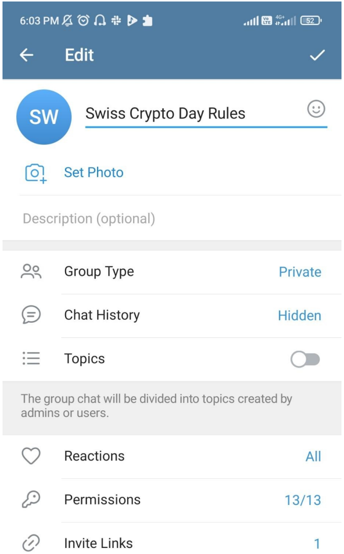
- **Correctness and security notions** matching modern messaging standards (forward security, post-compromise security).
- Two modular, **provably-secure constructions**, IAS and DGS.
- Efficient **integration with MLS**, benchmarking, and admin extensions.

Group Messaging

Group Administration?





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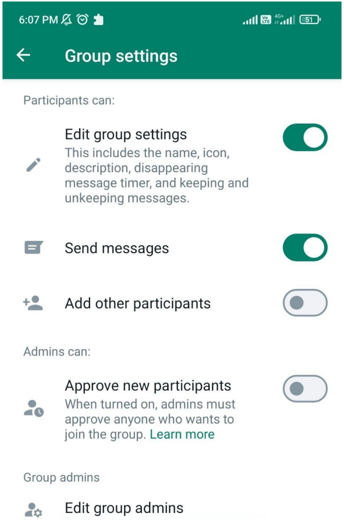

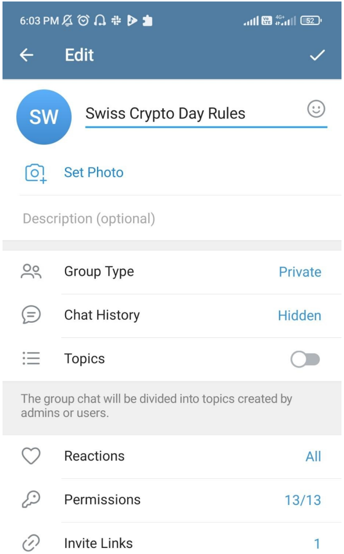

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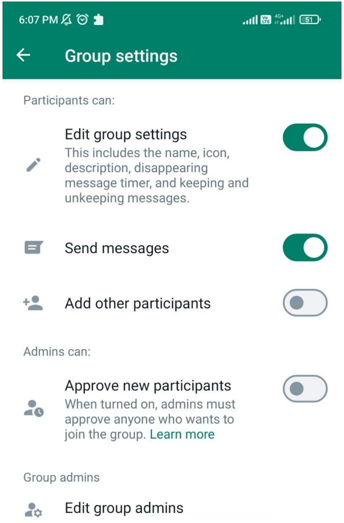

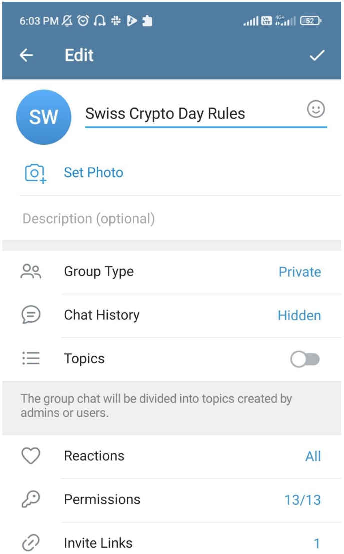

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- In this talk: only *admins* should be able to **add and remove users** (and admins).

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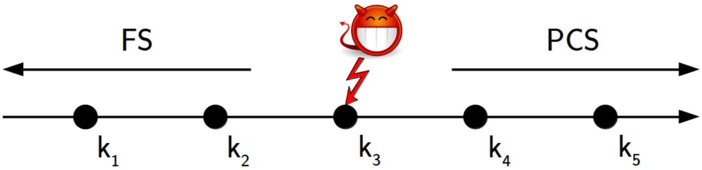

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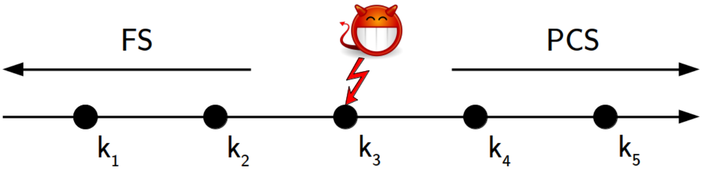

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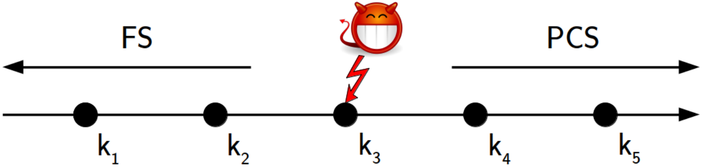

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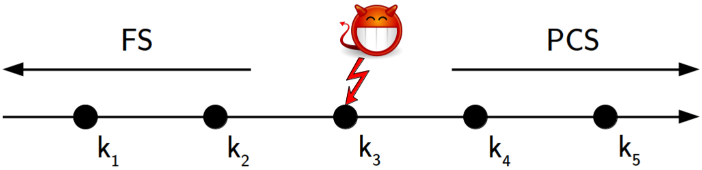

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- **Group dynamics:** cryptographic adds and removes from group G.
- ***Administration:*** only admins $G^* \subseteq G$ can make group changes.

Towards MLS (Message Layer Security)

Existing group messaging protocols:

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- Interest from academia and industry.

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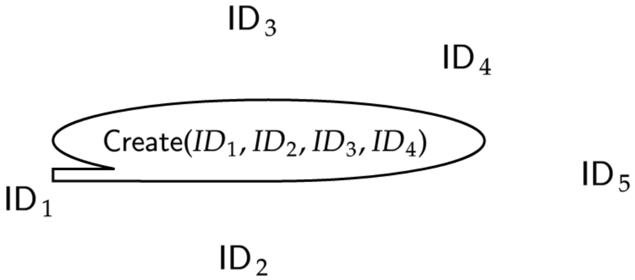
CGKA (simplified):

- $\mathsf{Init}(1^\lambda, ID)$
- $\mathsf{Create}(G) \rightarrow T$
- $\mathsf{Prop}(ID, \mathsf{type}) \rightarrow P$
- $\mathsf{Commit}(\vec{P}) \rightarrow T$
- $\mathsf{Proc}(T) \rightarrow I'$

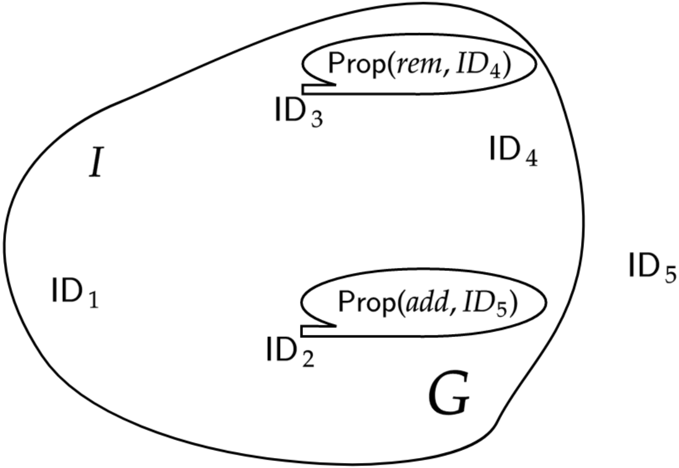
CGKA: Create

- ID_1 creates a group $G = \{ID_1, ID_2, ID_3, ID_4\}$.



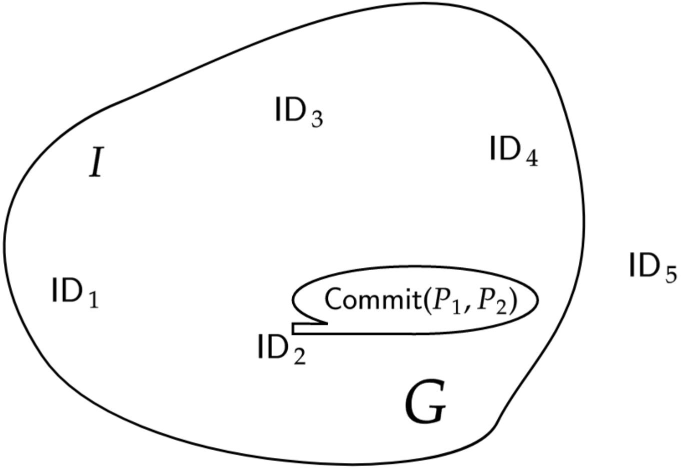
CGKA: Proposals

- ID_2 and ID_3 propose changes.



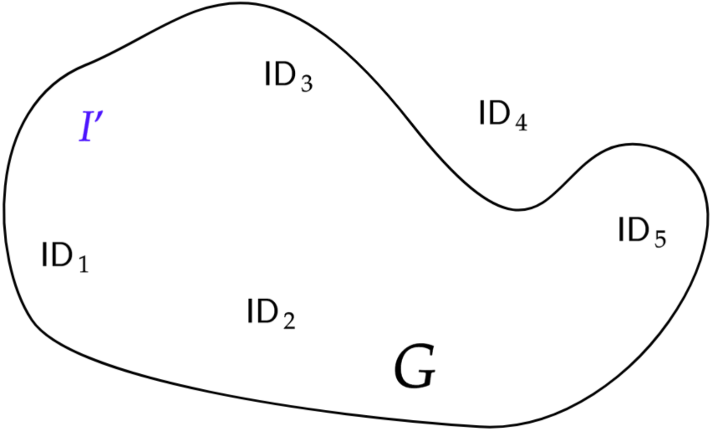
CGKA: Commit

- ID_2 commits both proposals.



CGKA: Process Changes

- The group evolves to a new *epoch* and I' is refreshed.



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Administration security: Non-admins cannot commit (except updates and self-removes).

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$\mathcal{O}^{\mathsf{Inject}}(\mathsf{ID}, m, t_a)$

1 : **require** $\mathsf{C}_{\mathsf{adm}} \wedge (\mathsf{ep}[\mathsf{ID}] = (\cdot, t_a)) \wedge (t_a \neq -1)$
2 : **require** $(m, \cdot) \notin \mathsf{T}$ // external forgery
3 : $(\gamma, \perp) \leftarrow \mathsf{proc}(\mathsf{ST}[\mathsf{ID}], m)$
4 : **if** $\mathsf{C}_{\mathsf{forgery}}$
5 : $\quad$ $\mathsf{forged} \leftarrow \mathsf{true}$ // successful forgery
6 : $\quad$ **return** b // adversary wins
7 : **else return** $\perp$

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$$\mathsf{KIND}^{\mathcal{A}}_{\mathsf{(A)\text{-}CGKA},\mathsf{C}_{\mathsf{cgka}},\mathsf{C}_{\mathsf{adm}},\mathsf{C}_{\mathsf{forgery}}}(1^\lambda)$$

- A key indistinguishability game.
- Formally captured in *cleanness predicates*.
- Cannot inject commits **even if non-admins are corrupted** (except for non-admin updates and self-removes).
- Security is restored after compromised users (and admins) *update* or are *removed* (PCS).

$\mathsf{C}_{\mathsf{cgka\text{-}opt}}$ $\mathsf{C}_{\mathsf{adm\text{-}opt}}$ $\mathsf{C}_{\mathsf{forgery}}$

$\mathcal{O}^{\mathsf{Inject}}(\mathsf{ID}, m, t_a)$

1 : **require** $\mathsf{C}_{\mathsf{adm}} \wedge (\mathsf{ep}[\mathsf{ID}] = (\cdot, t_a)) \wedge (t_a \neq -1)$
2 : **require** $(m, \cdot) \notin \mathsf{T}$ // external forgery
3 : $(\gamma, \perp) \leftarrow \mathsf{proc}(\mathsf{ST}[\mathsf{ID}], m)$
4 : **if** $\mathsf{C}_{\mathsf{forgery}}$
5 : $\mathsf{forged} \leftarrow \mathsf{true}$ // successful forgery
6 : **return** b // adversary wins
7 : **else return** $\perp$

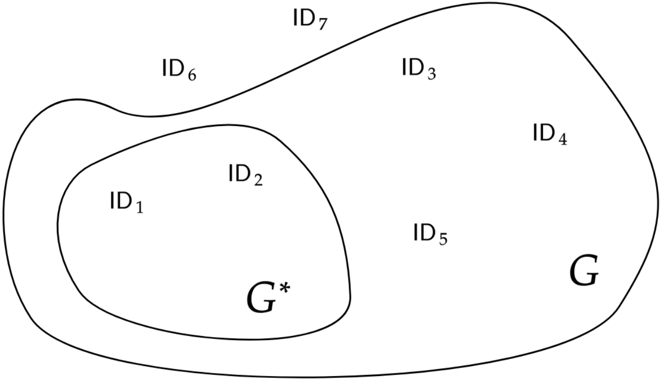
$\mathsf{hasUpd}_{\mathsf{std}}$ $\mathsf{hasUpd}_{\mathsf{adm}}$

Protocols for Secure Administration

We introduce **IAS** (*Individual Admin Signatures*) and **DGS** (*Dynamic Group Signature*).

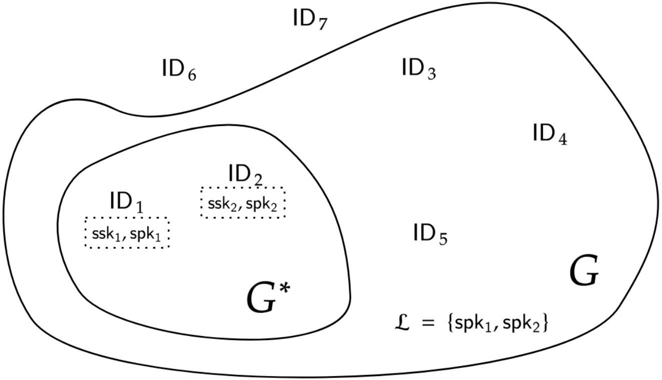
- Modular.
- Authenticate administrators (with different efficiency trade-offs).
- Allow for admin key refresh for PCS and FS.

Individual Admin Signatures (IAS)



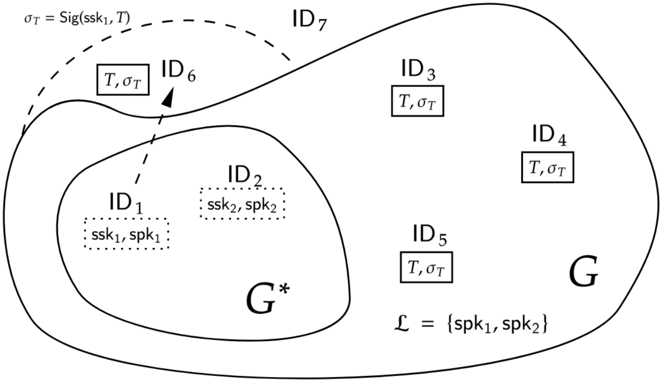
- We construct A-CGKA on top of any CGKA.
- Based on signatures.

IAS



- Admins have individual signature key pairs $(\mathsf{ssk}, \mathsf{spk})$.
- Users keep an admin list $\mathcal{L}$.

IAS: Add Participant



- Admin signs commit T with $\mathsf{ssk}_1 \longrightarrow \sigma_T$.
- Users verify σ_T with spk_1 from $\mathcal{L}$.

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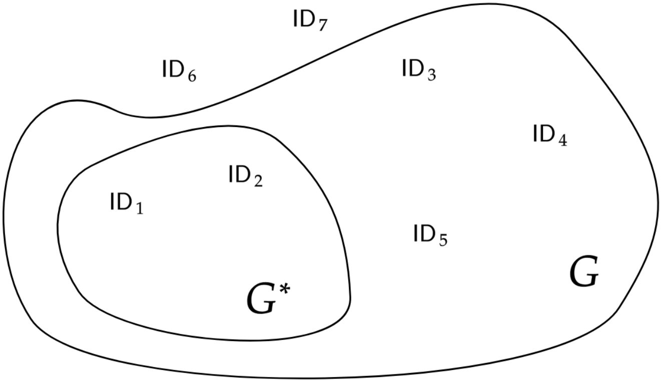
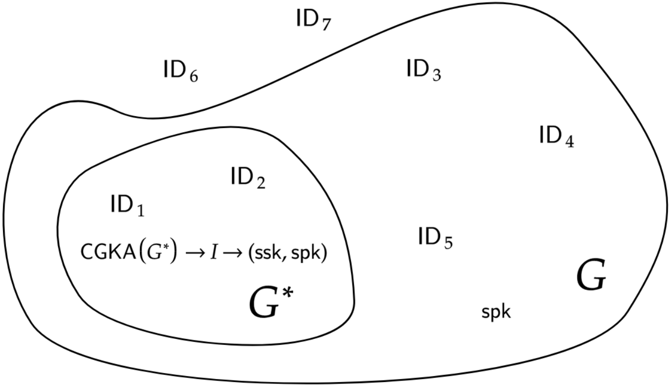
- Can use forward-secure signatures for better (optimal) forward security.

Dynamic Group Signature (DGS)



- In DGS, all admins in G^* use the *same* signature key pair.
- Built from two CGKAs: the *core* CGKA $CGKA$ and the *admin* CGKA $CGKA^*$.

DGS



- Admin operations are managed through G^*.
- New admin public keys *spk* are signed under the old key.

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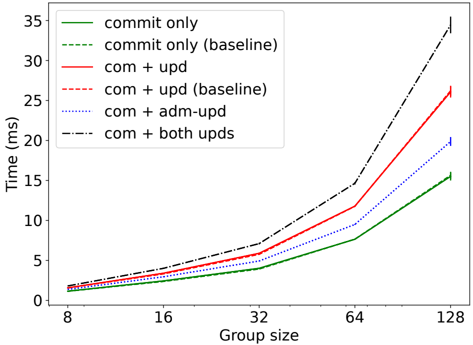
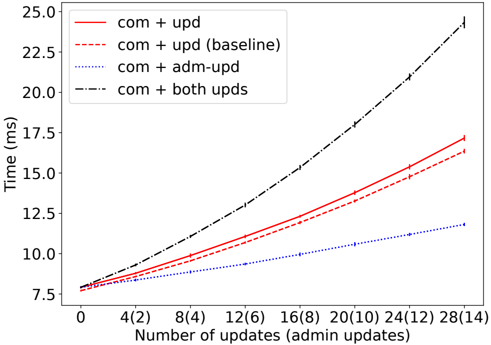
- Extended proposal types.
- Could be integrated as an *MLS extension*.
- **Minimal overhead** (from benchmarking):
  - We forked CISCO's golang MLS implementation.
  - Benchmarking setup: 11th Gen Intel i5-1135G7, 16GB RAM.
  - Operations are executed by a single party.

Benchmarking (commits)





- upd: $|G|/4$ updates; adm-upd: $|G|/8$ admin updates.
- *Less than 20%* overhead when $|G|/8$ admins update simultaneously.
- *Additional communication* $< 3\%$ for $|G| = 128$ members.
- Overhead comes from admins performing CGKA updates.

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- IAS admin overhead:
  - Admin proposal: key pair generation and signing.
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- Admin operations may be less frequent than regular ones.
- Forward-secure signatures: constant asymptotic overhead but non-standard.

Admin Extensions and Future Work

Our work serves to initiate the study of provably-secure administration:

- Admins beyond CGKA.
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- Advanced admins:
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  - Hierarchical admins.
- Preventing insider attacks with trusted admins.

Conclusion

- Securing *membership* is essential in group messaging security.
- We treat cryptographic *administration* as a first-class (provable) security property.
- Can be implemented with small overhead.
- Modular solutions *readily compatible* with CGKAs and MLS.

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Thank you!

ia.cr/2022/1411

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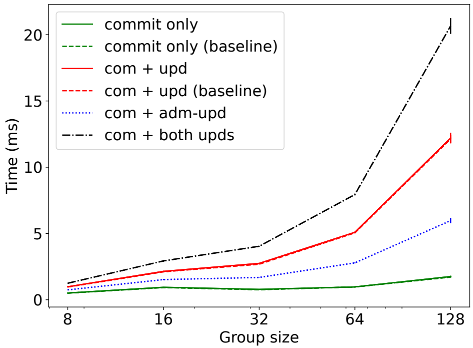
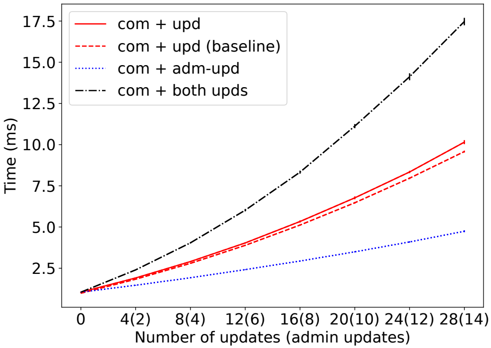
Backup Slides

Some additional slides follow.

Benchmarking (process)





- Comparable behaviour to commits.

On PKI

- We assume an incorruptible PKI.
- This follows previous work, except [AJM22] and [ACDT21] that allow malicious key uploads.
- Naturally, no security guarantees can be provided for users associated with these keys.
- All users always are assumed to share the same view of the PKI in all works we are aware of.