Keep the Dirt: Tainted TreeKEM, Adaptively and Actively Secure Continuous Group Key Agreement

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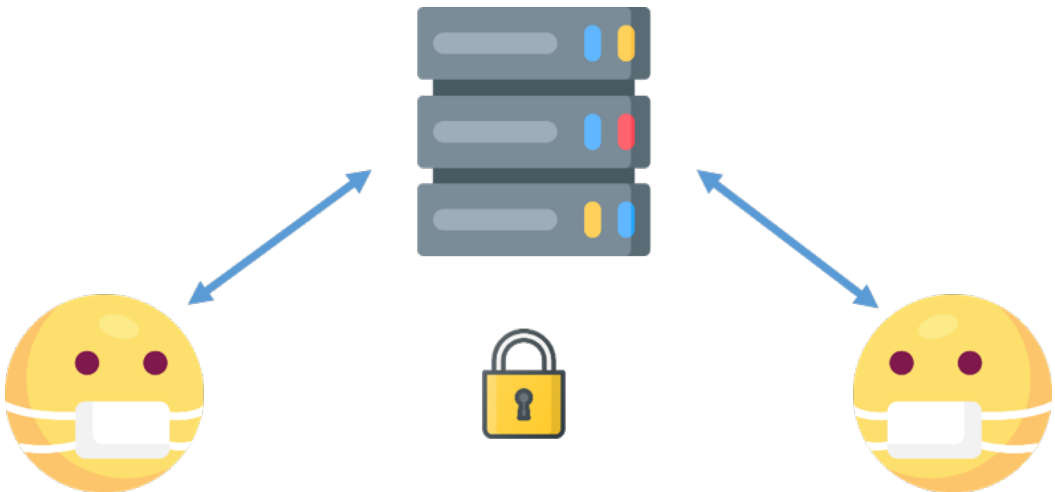
Secure messaging



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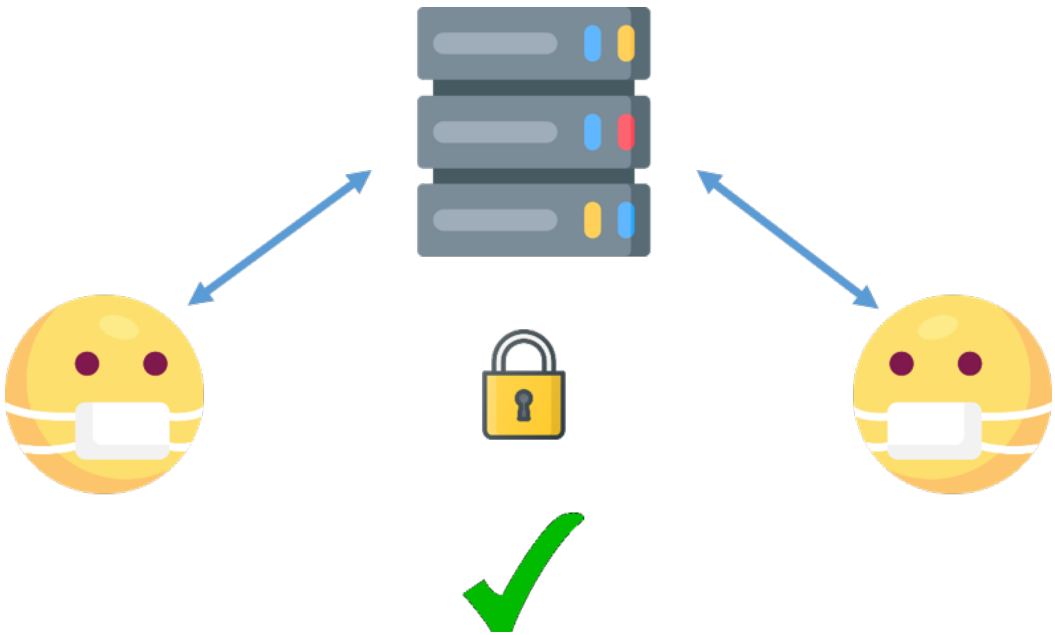

M. Marlinspike and T. Perrin - *The double ratchet algorithm*, Signal.
[BSJNS17, CCDGS17, DV18, JS18, PR18, ACD19,...]

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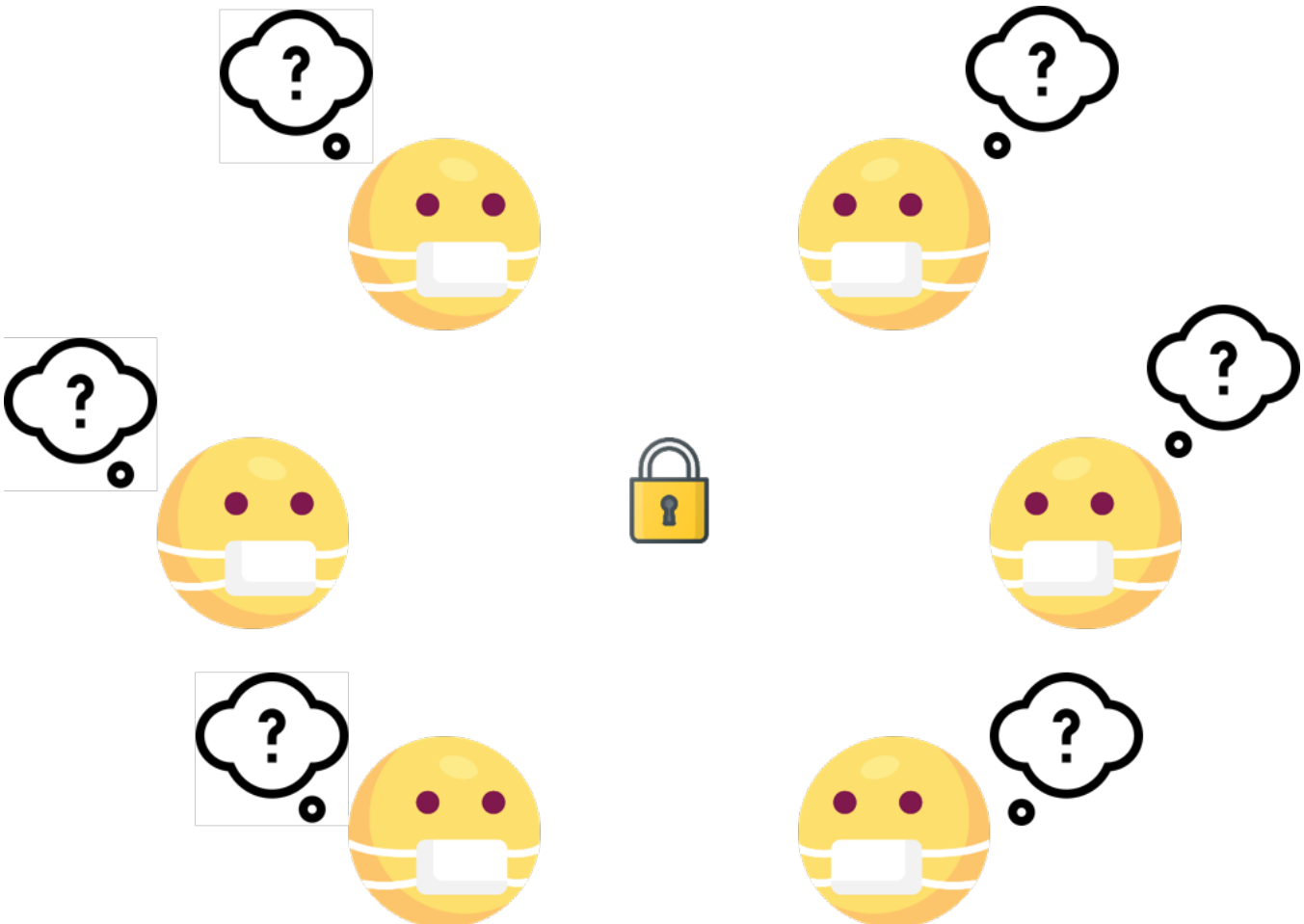

In this talk I will...

- Overview **Continuous Group Key Agreement** (CGKA).
- Present **Tainted TreeKEM**, an efficient CGKA protocol.
- Discuss efficiency and security

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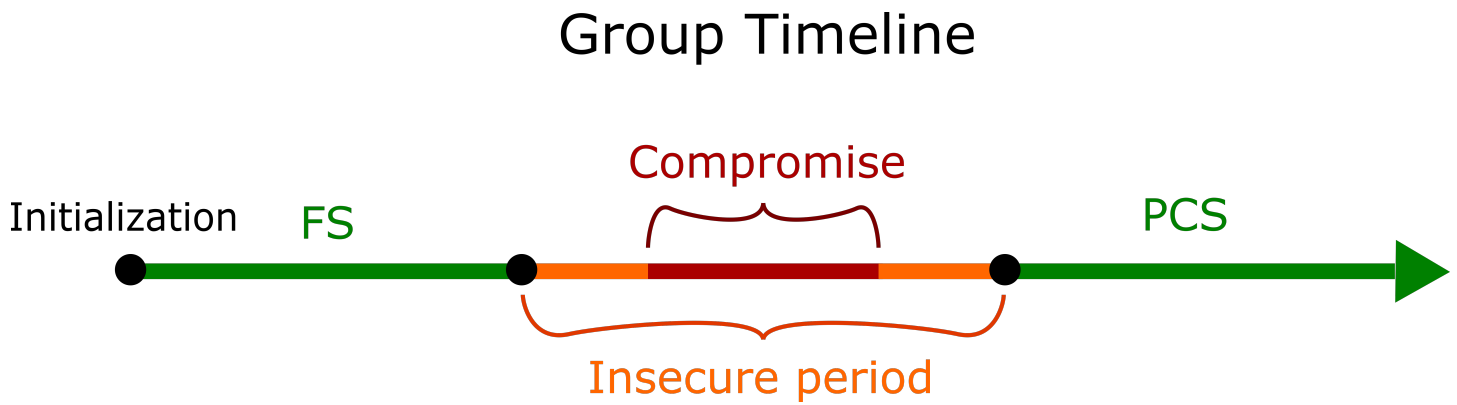

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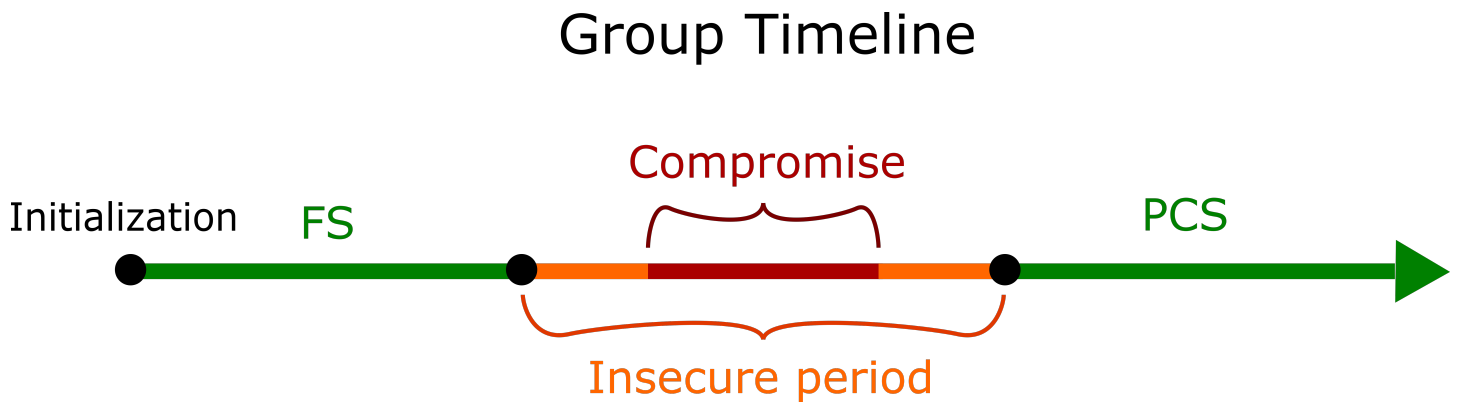

Need **key update** functionality

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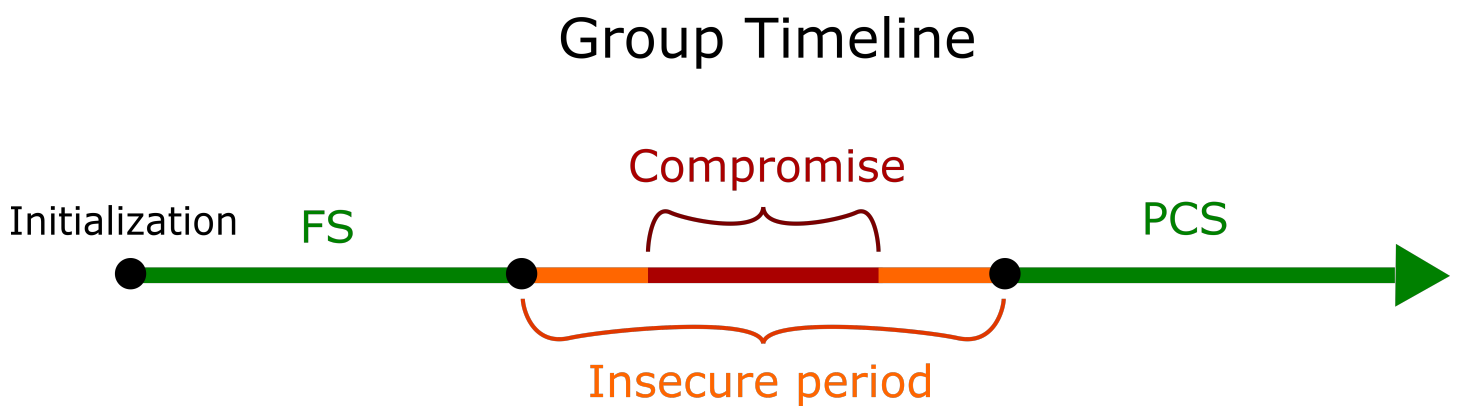
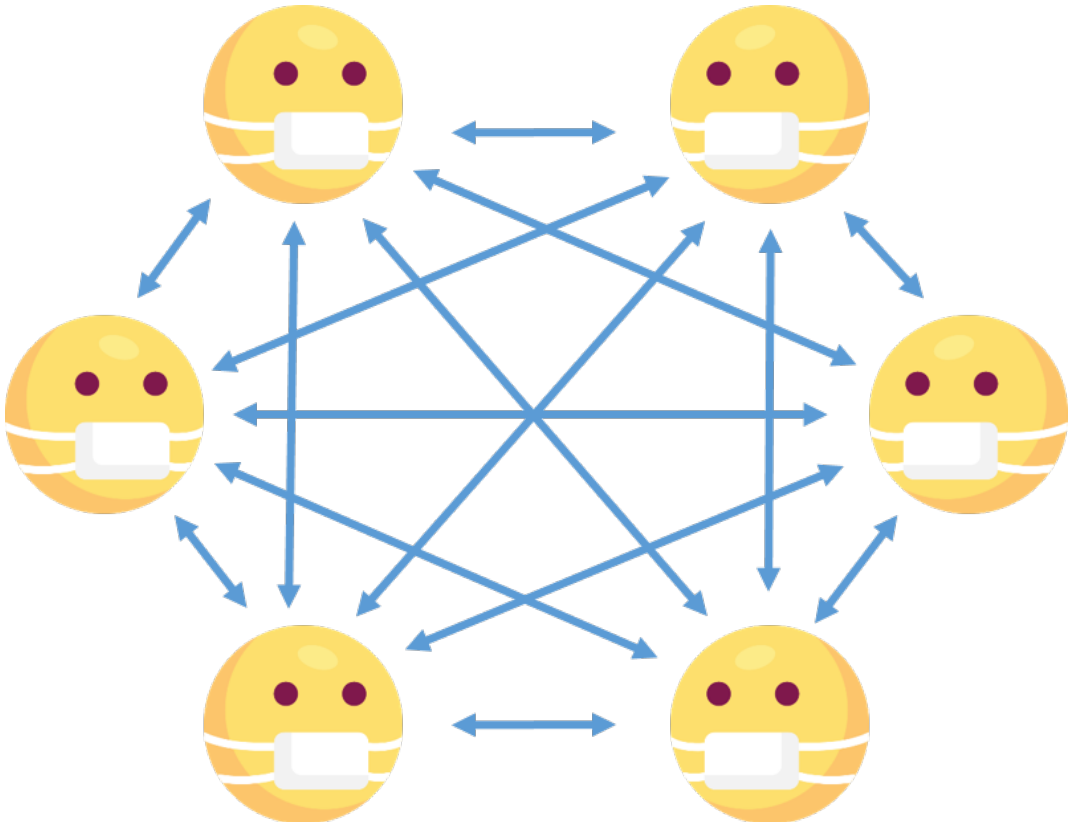


Need **key update** functionality

- **FS**: One-way deterministic enough.
- **PCS**: Needs **new randomness**.

n-party CGKA: Bidirectional channels?



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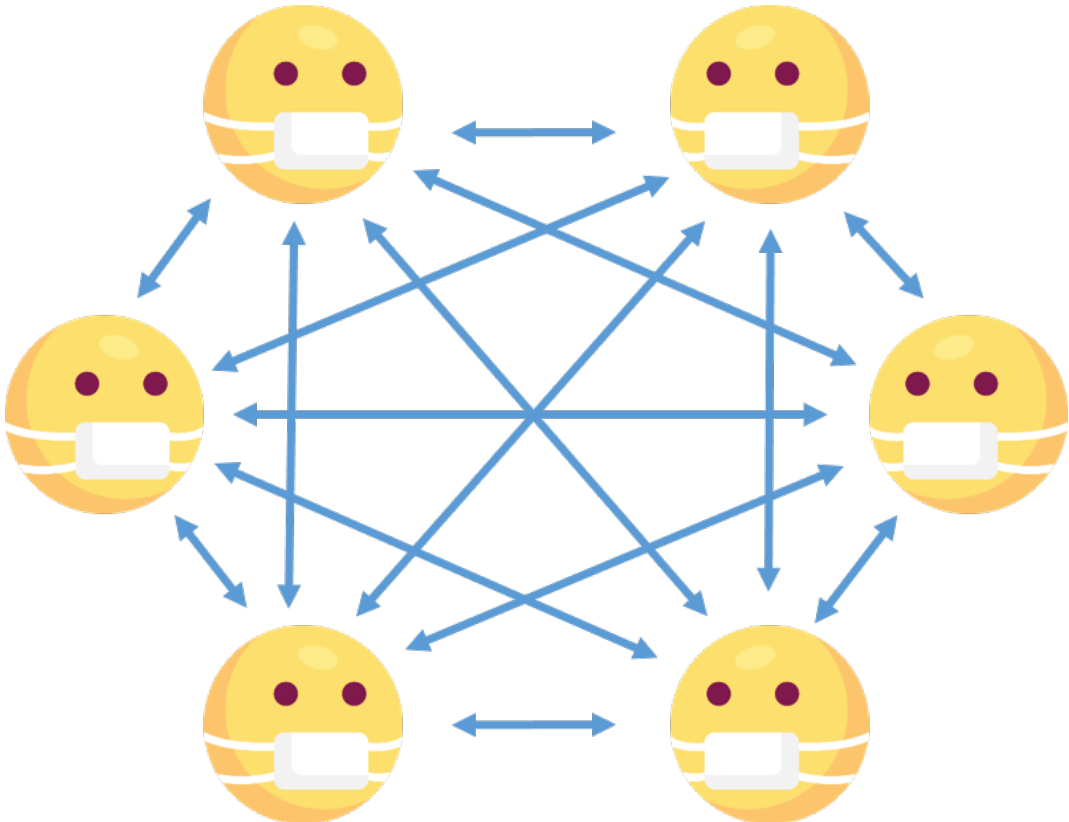

Key updating incurs **linear communication cost**!

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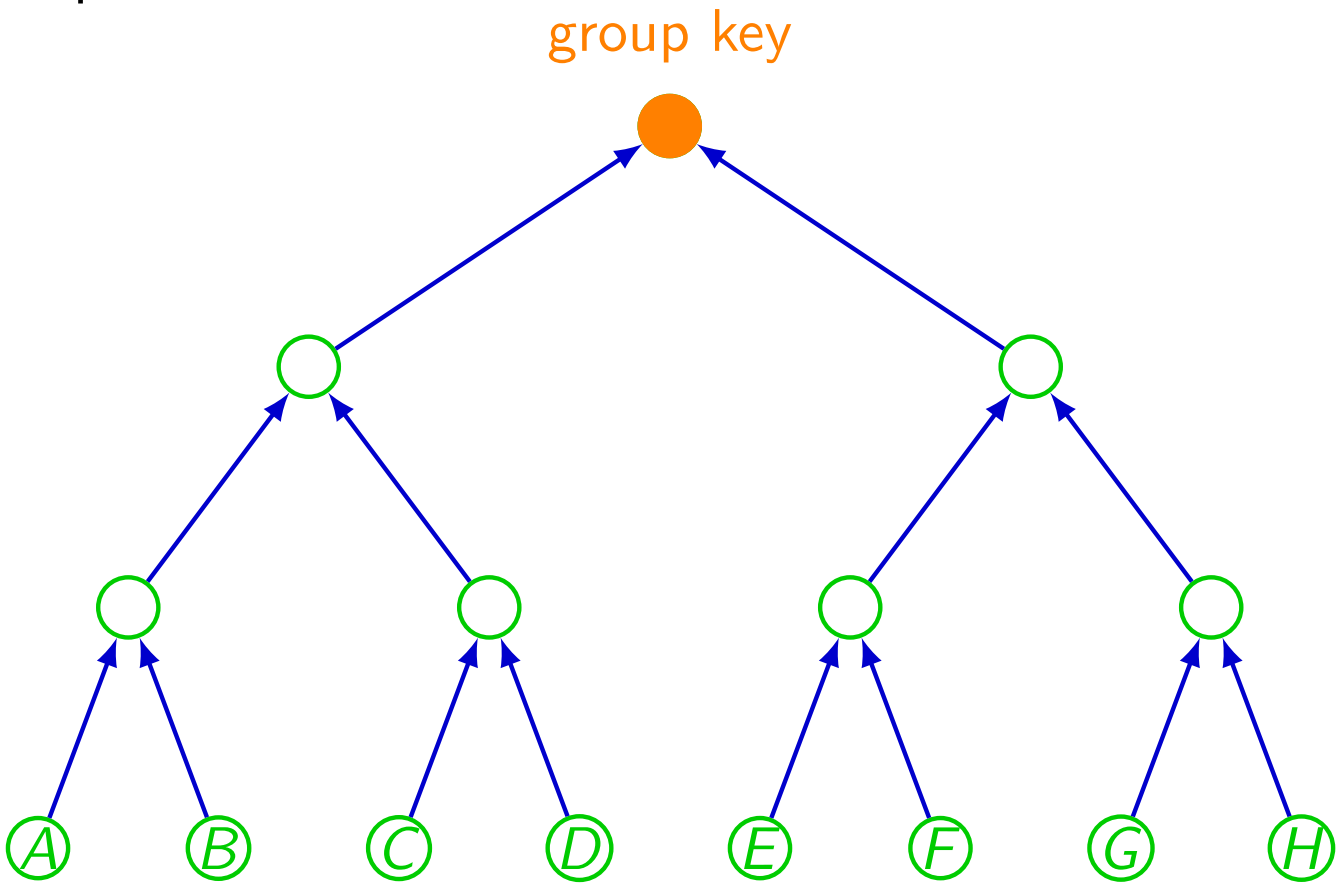
- Key updates with **efficient communication cost** (logarithmic).
  - More frequent updates $\rightarrow$ better security.

Message Layer Security (MLS)

- IETF Working group
- Standard for Secure Group Messaging
- Support for groups $\leq$ 50k users.
- Current Proposal: **TreeKEM**.

TreeKEM Protocol (MLS)

PKE key-pair per node.



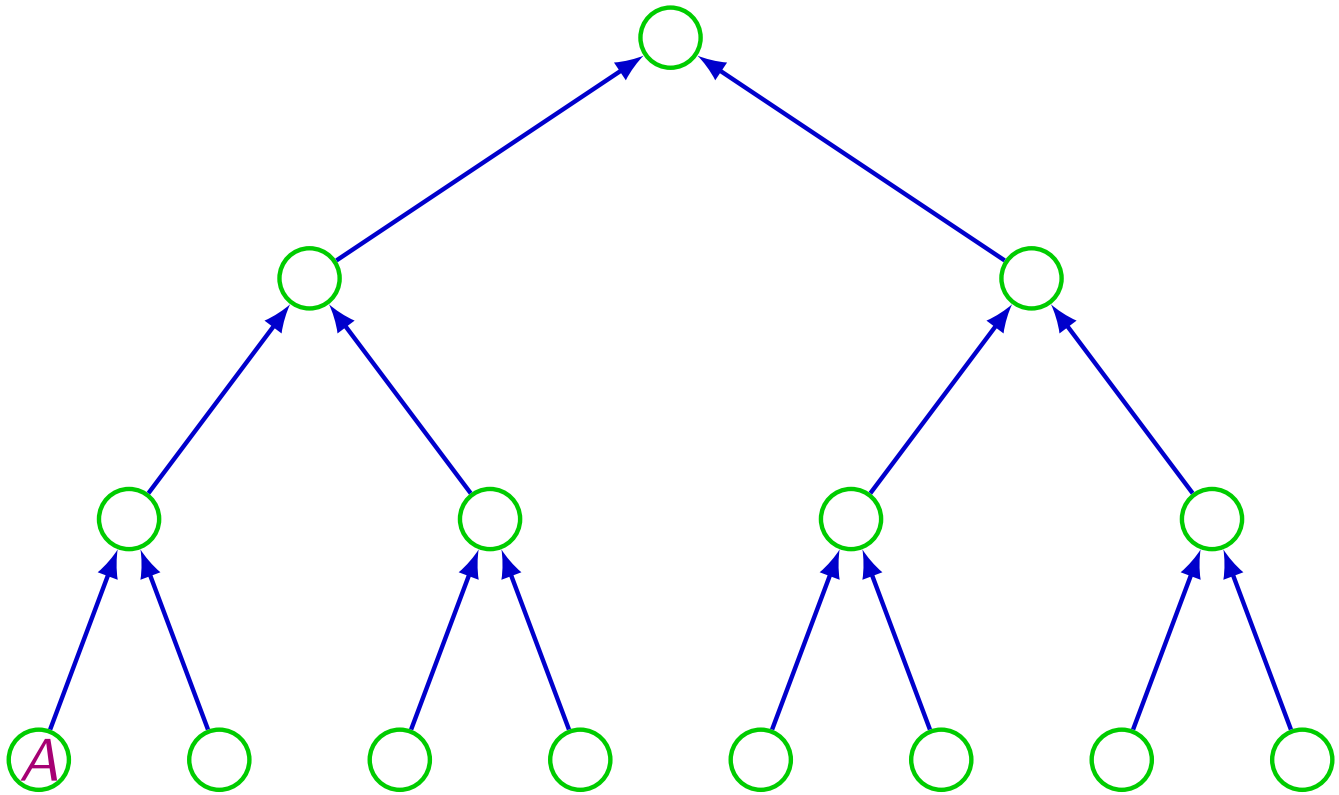
Edges meaning: Knowledge of source $\Rightarrow$ Knowledge of sink

$\Downarrow$

User knows secret keys on their **path to root**.

TreeKEM: Update (simplified)

Alice updates



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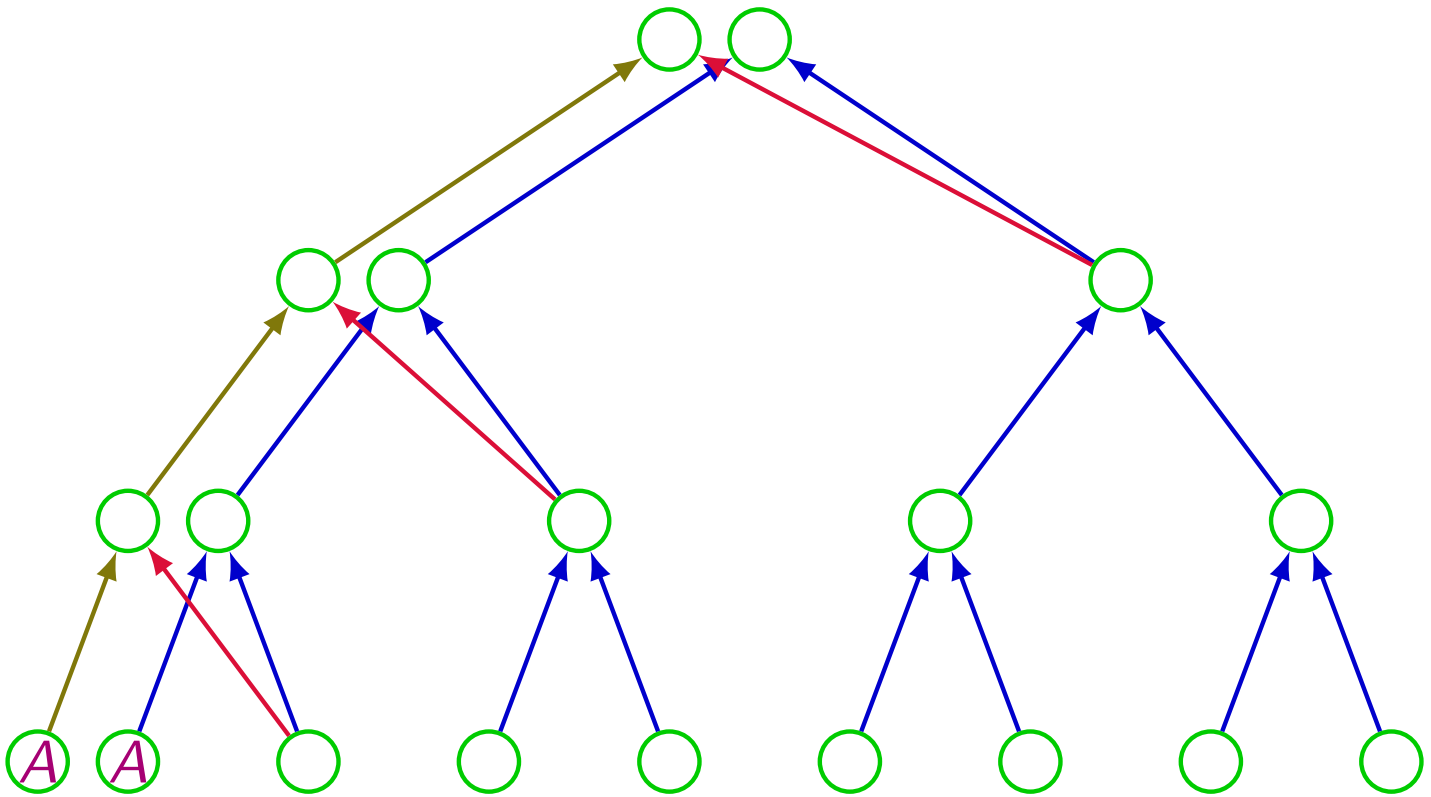
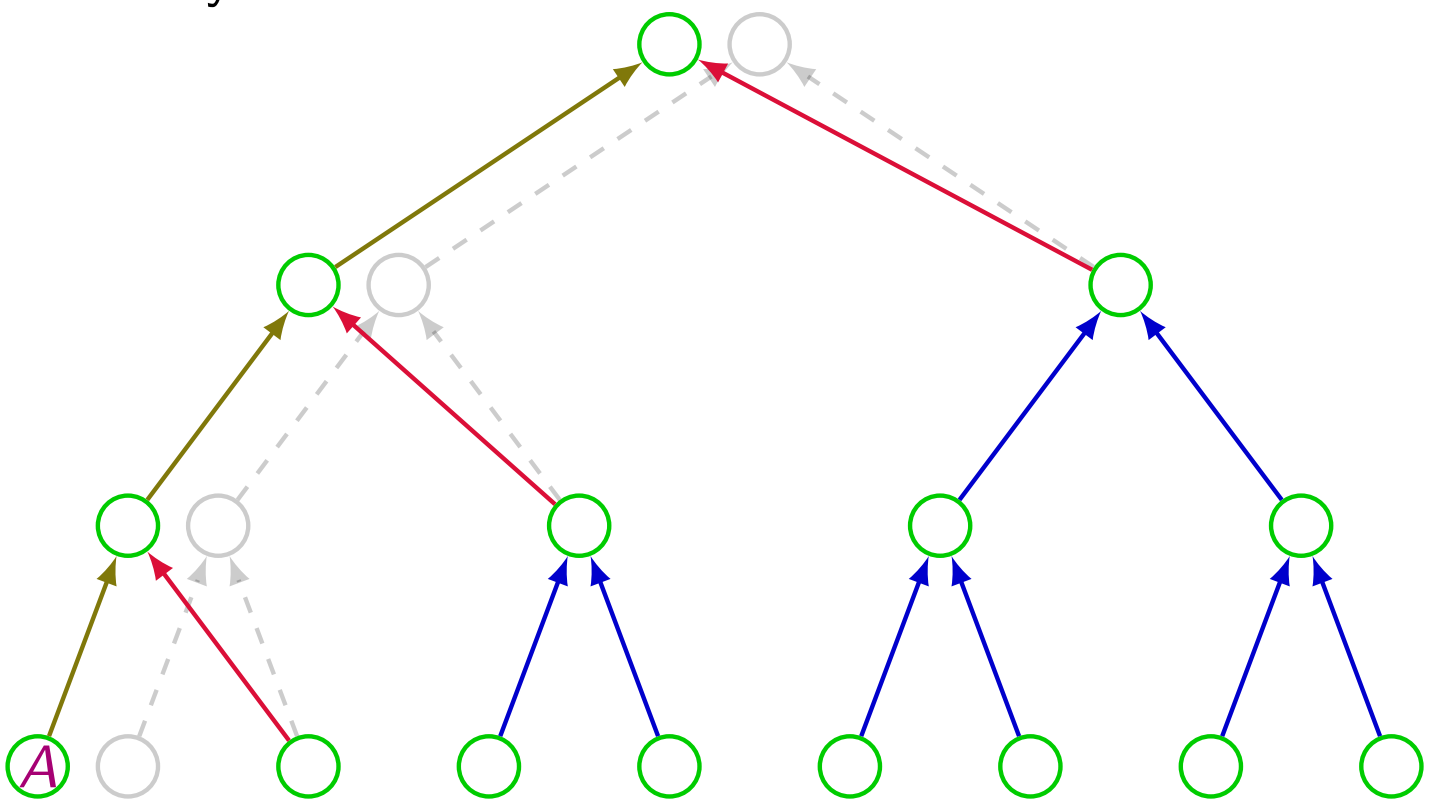


TreeKEM: Update (simplified)

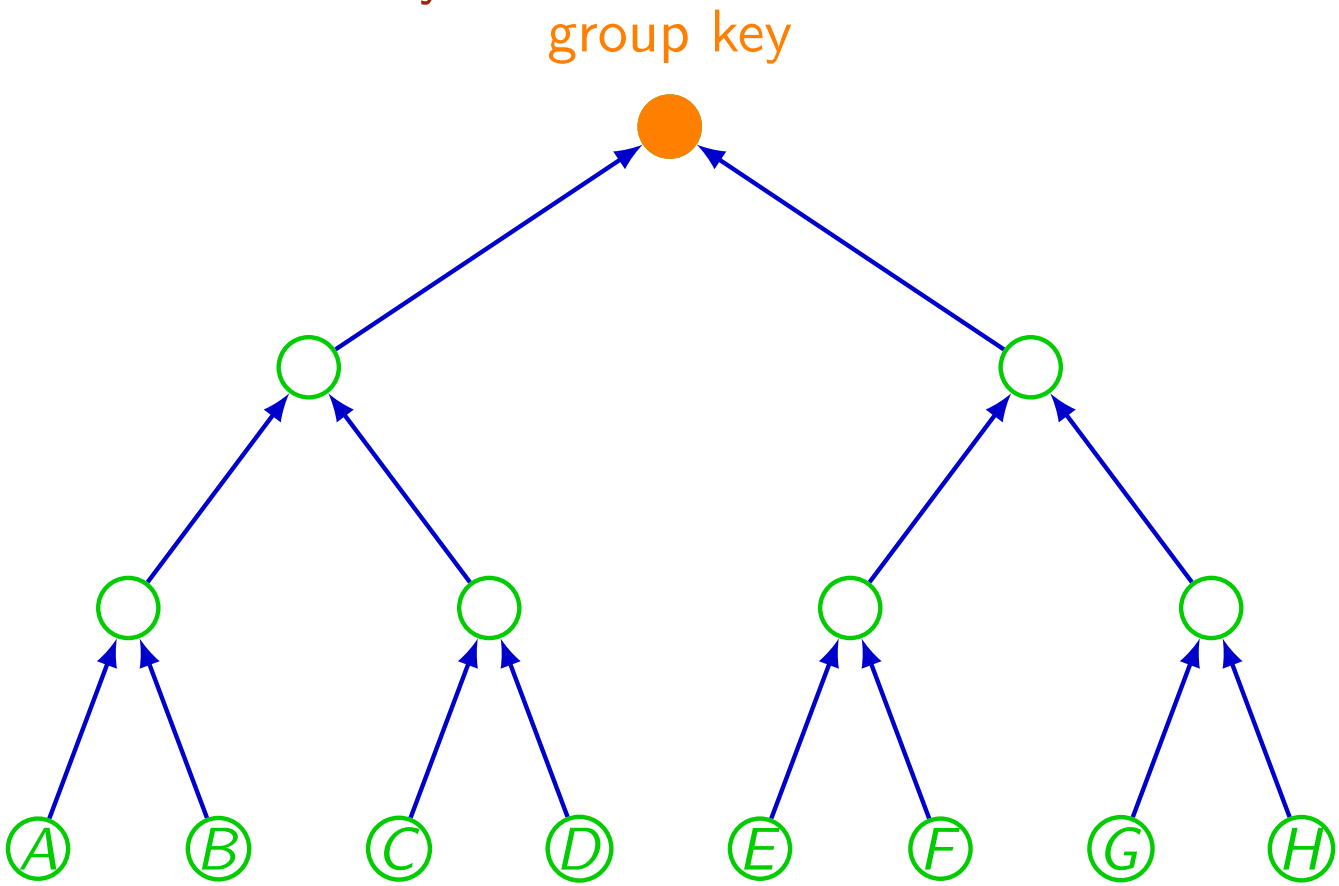
Alice updates

- chooses and encrypts fresh keys
- removes old keys



How to remove?

Alice wants to remove Henry



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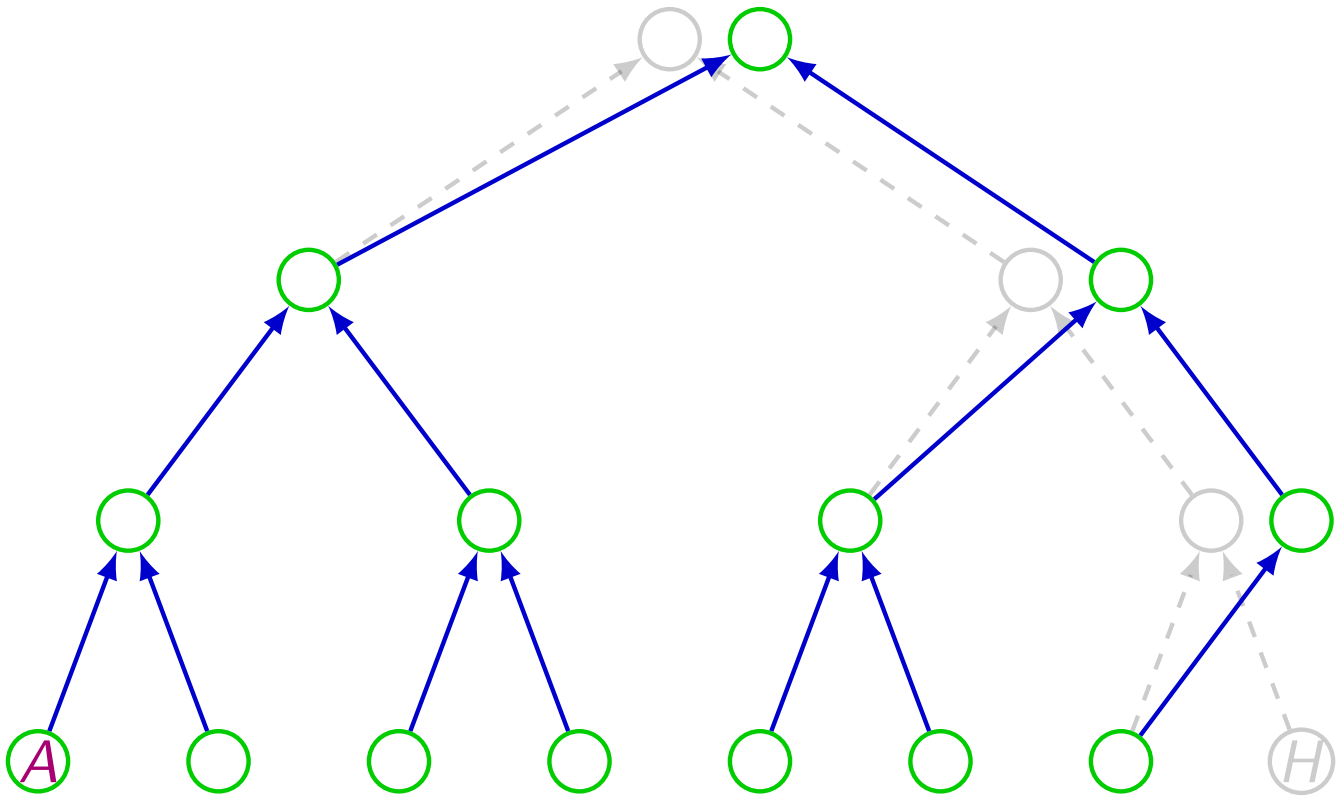
Alice needs to rotate keys in Henry 's path.



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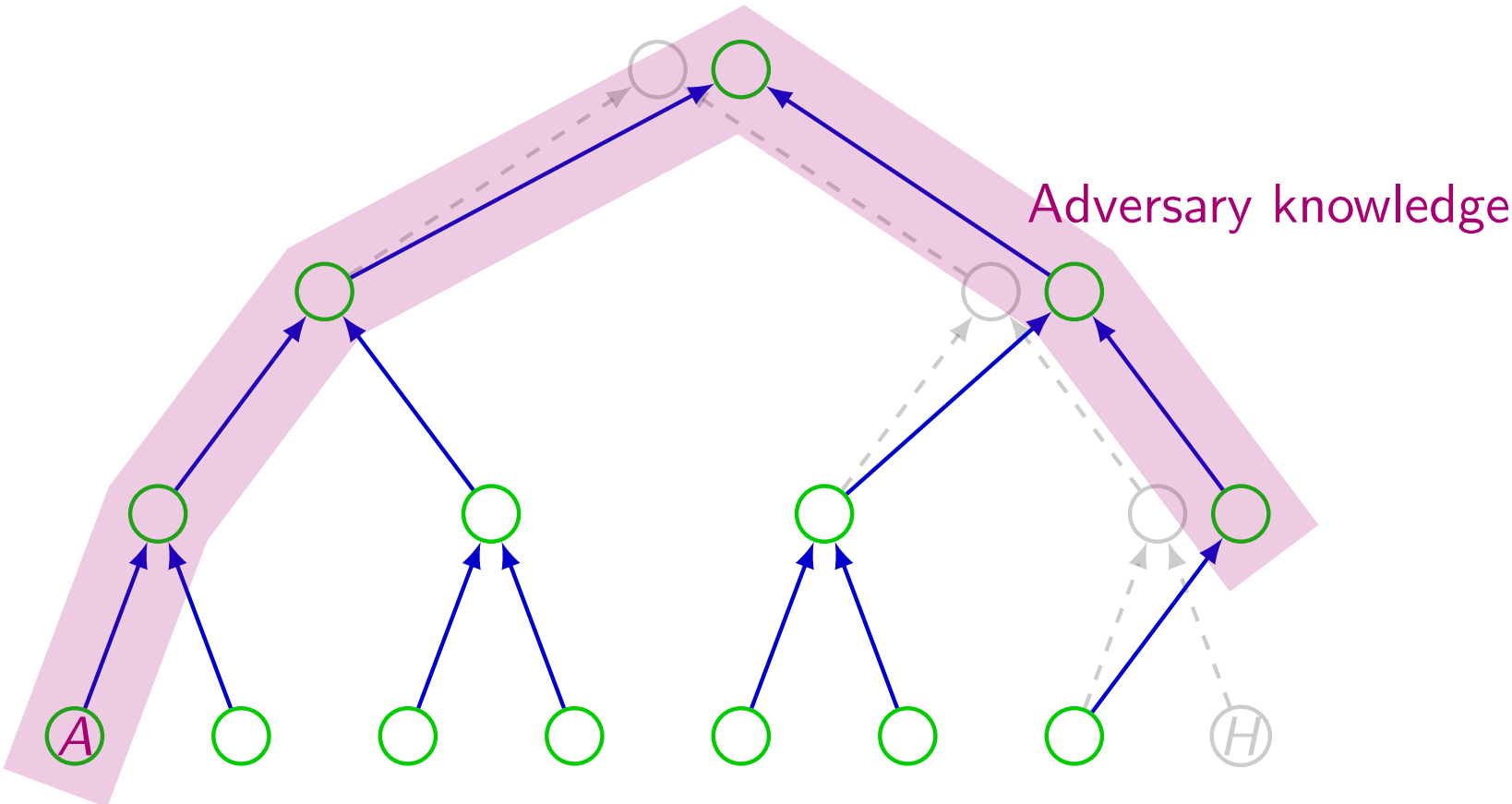
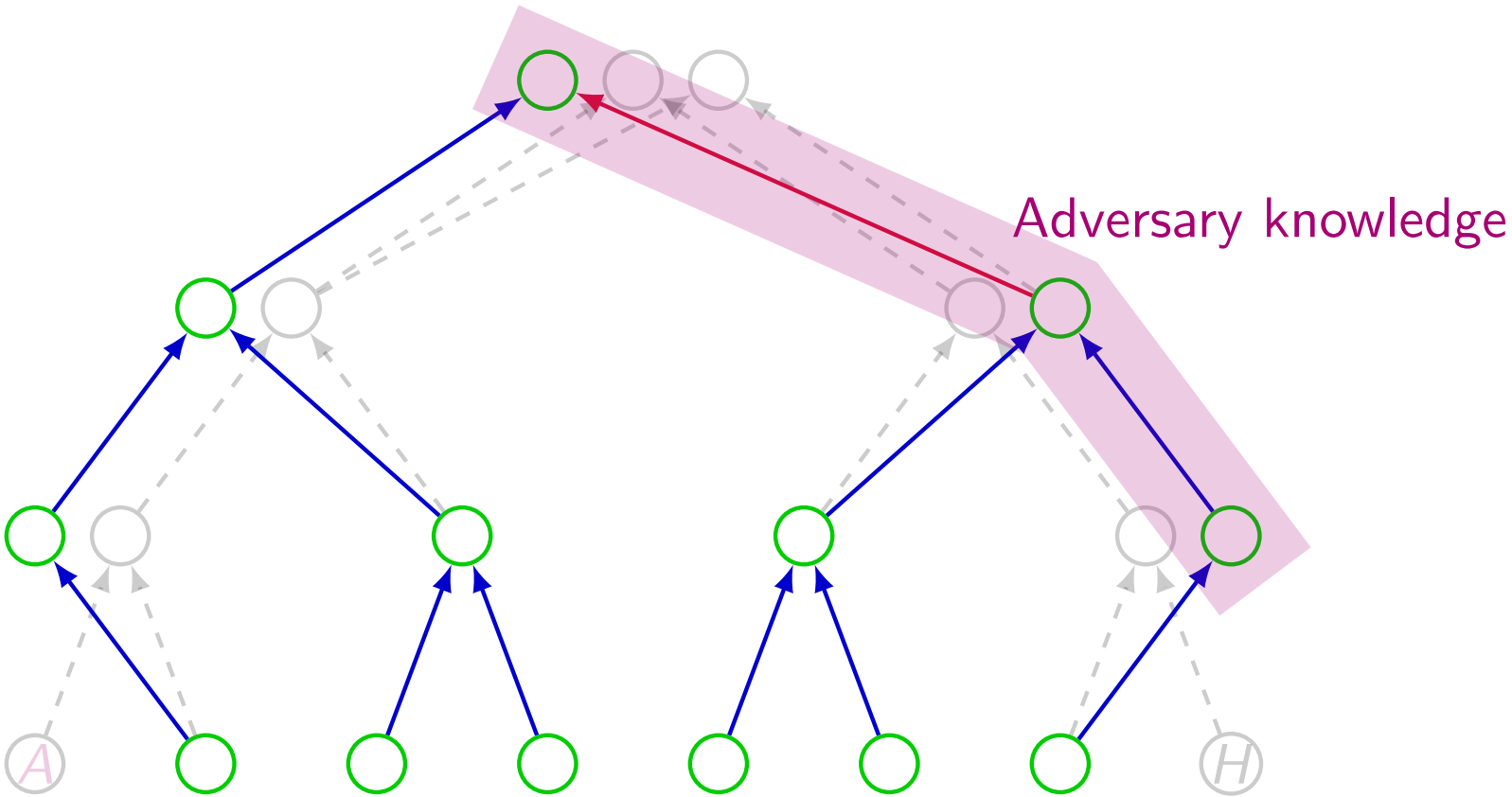


... if Alice corrupted, secret keys outside her path leak!

How to remove?

If Alice is now removed in the same way...

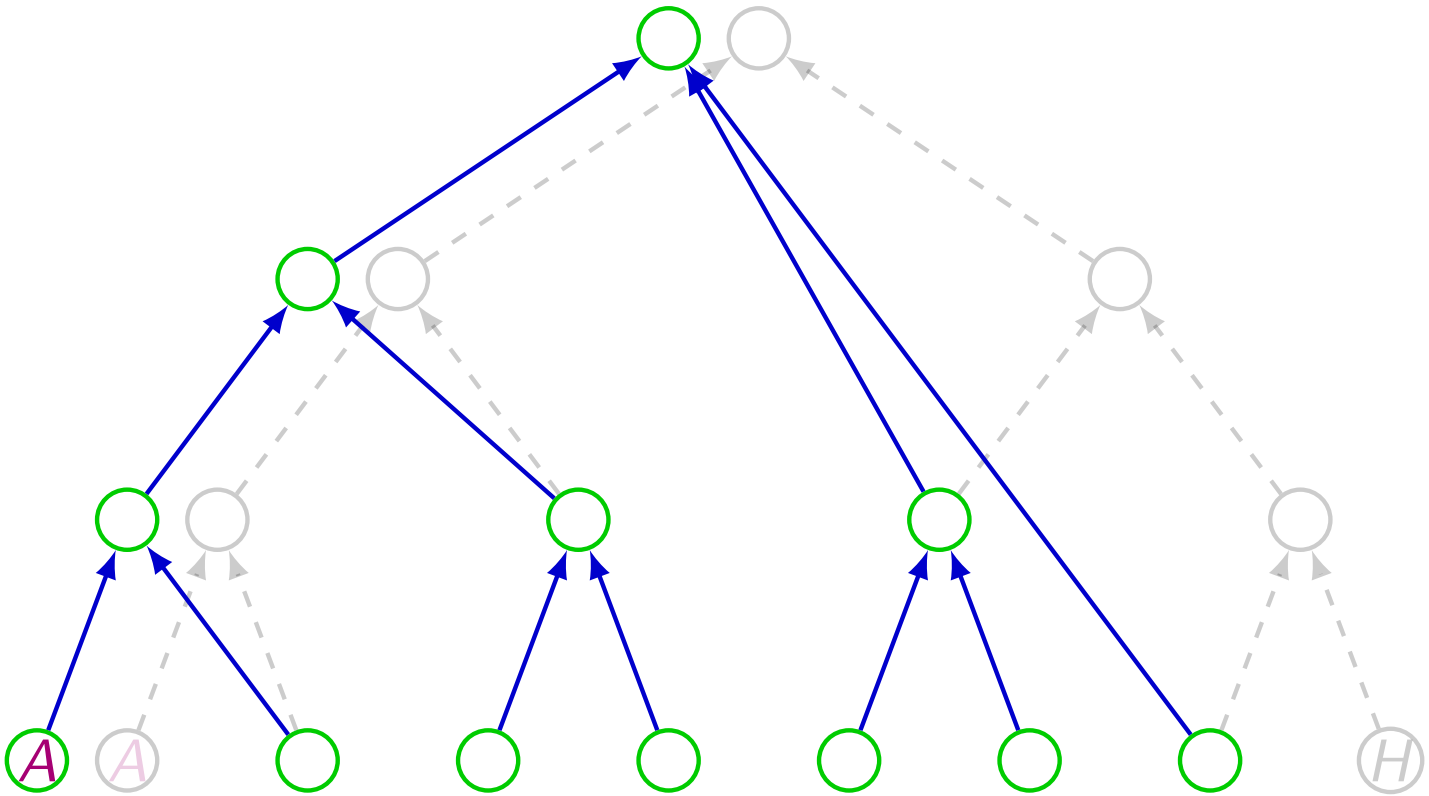


Adversary still has knowledge of the group key!

TreeKEM: Remove

Alice removes Henry by:

- "blanking"/deleting all nodes along Henry 's path.
- sampling a new group key.



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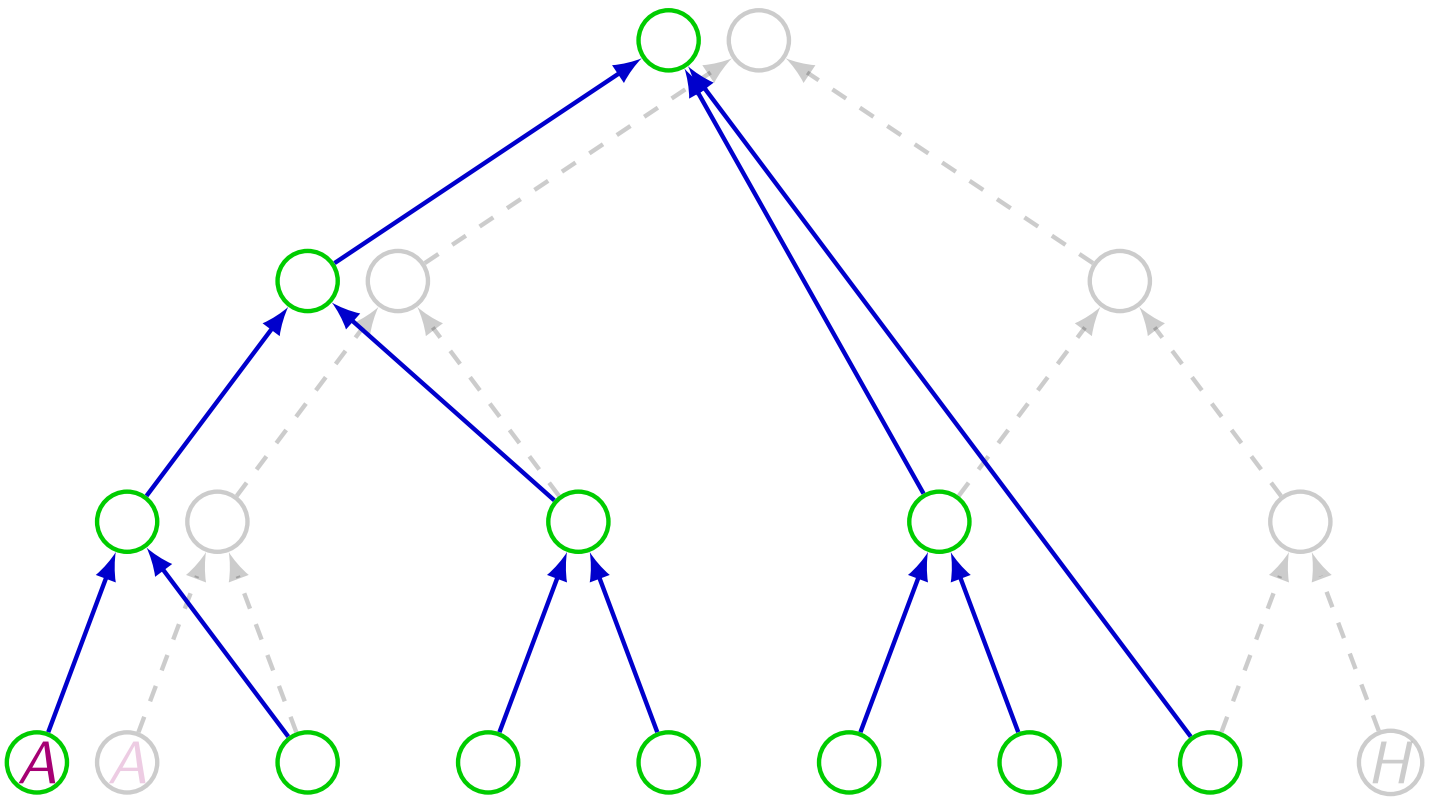
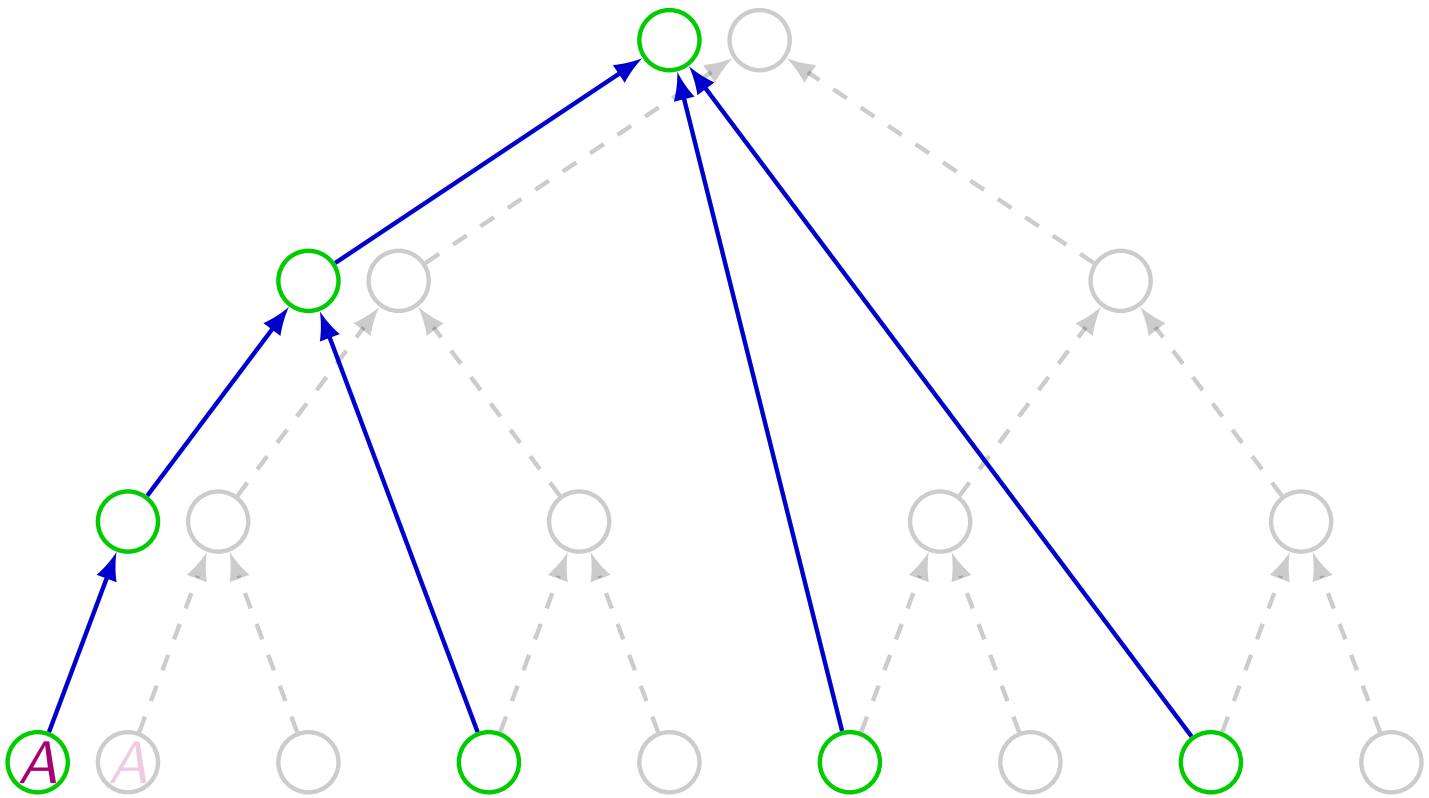


Blank nodes unblanked as parties update.

Problem: if many users removed...

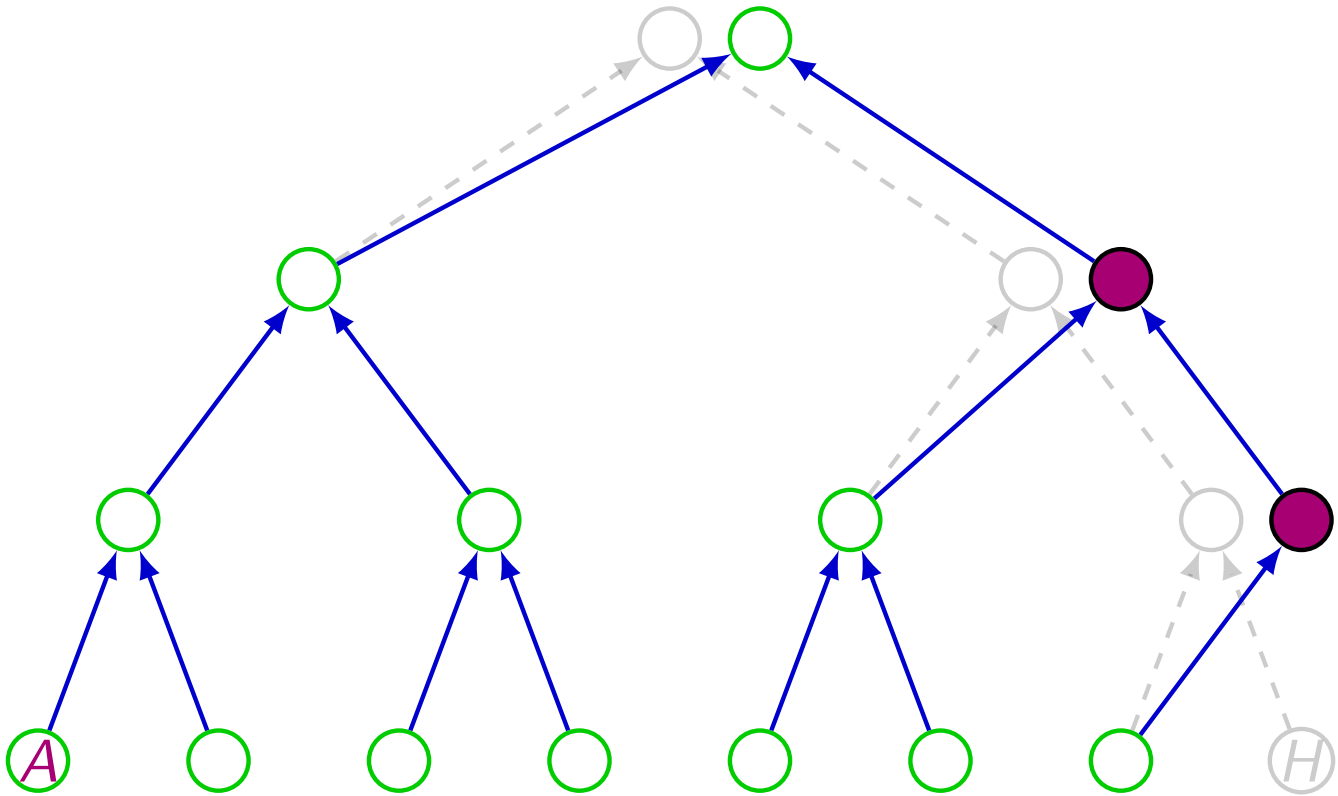


$\Rightarrow$ Linear packet size!!

Tainted TreeKEM (TTKEM) (this work)

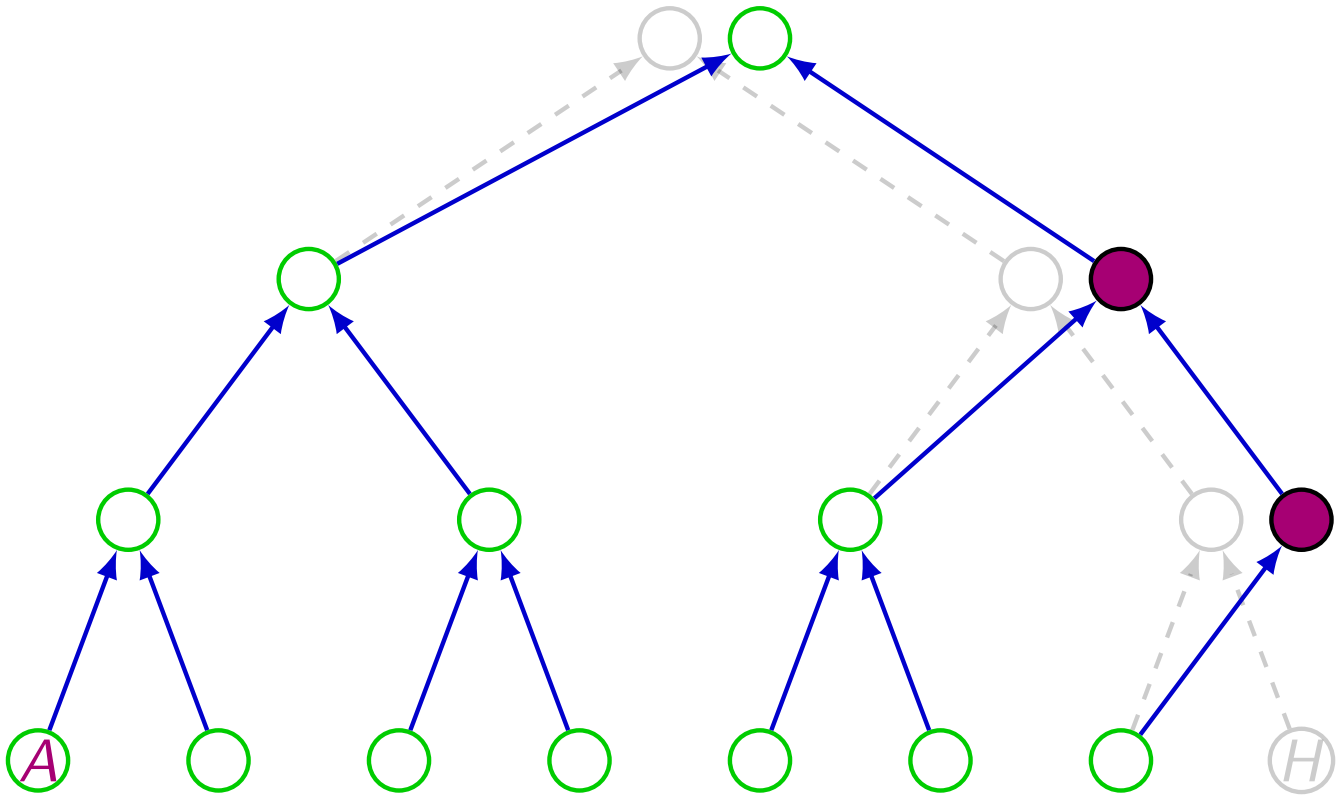
- CGKA variant of TreeKEM **without blanking**.
- More **efficient** under natural distributions of group operations.
- Secure against **adaptive** adversaries with **full network control**.
  - First adaptive proof for a CGKA/TreeKEM-related protocol with **polynomial loss**.

Tainted TreeKEM (TTKEM): Removal



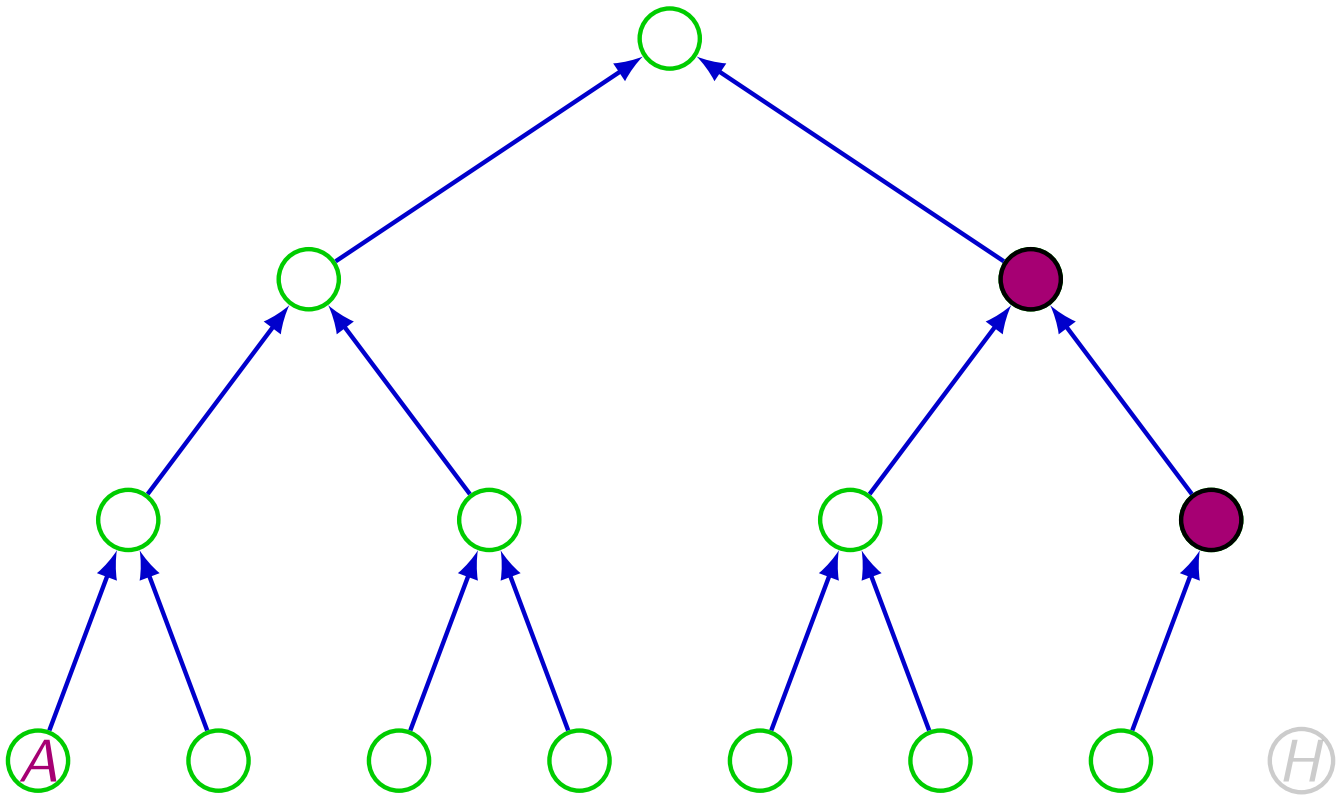
Tainted TreeKEM (TTKEM): Removal

- Allowed to sample keys outside own path $\rightarrow$ tainted nodes.
- Keep track of tainted nodes.



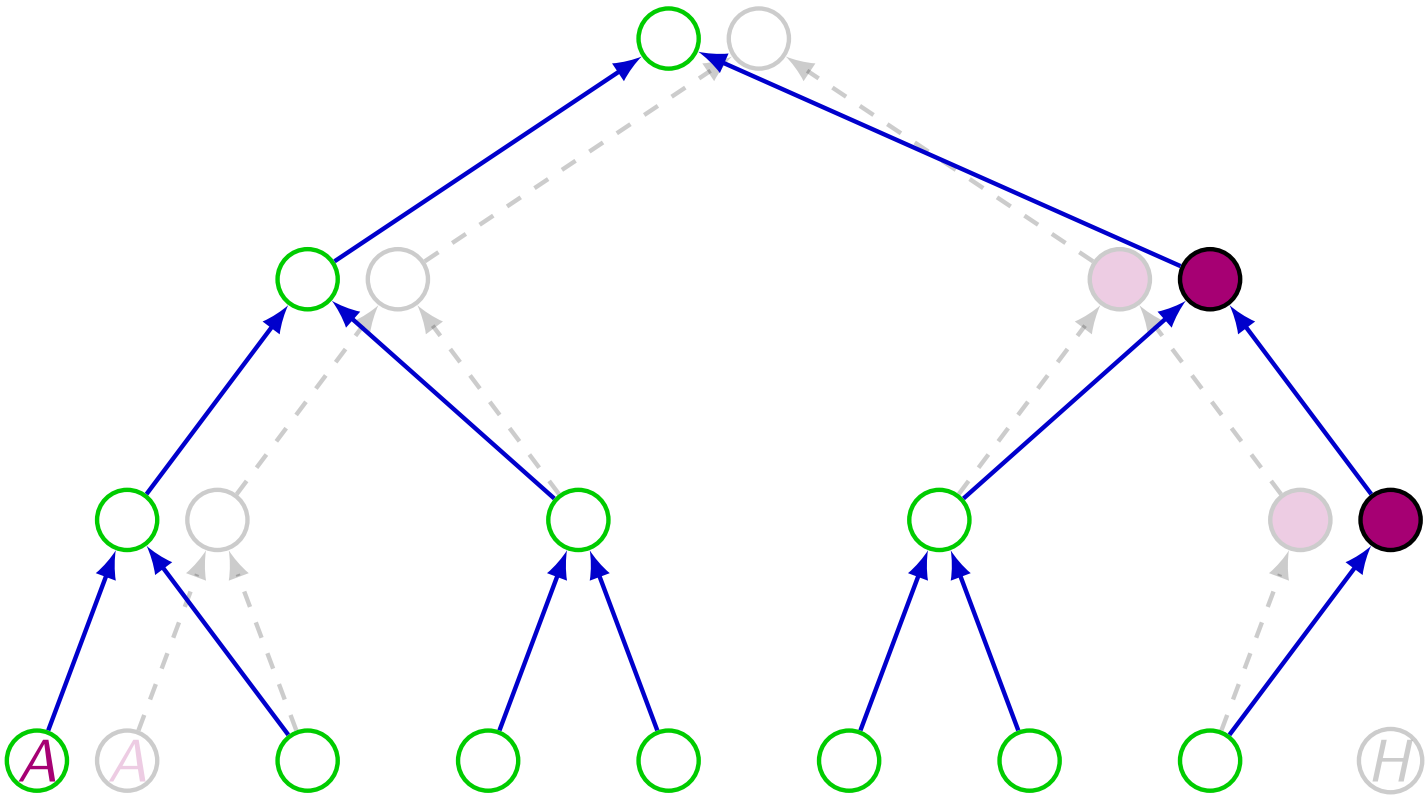
TTKEM: Update

Alice updates having tainted nodes



TTKEM: Update

Tainted nodes need to be re-sampled:



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- Who is **affected** by it?
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- When does a node **heal**?
  - A **blank** requires user in sub-tree to sample a new key for it.
  - A **taint** *also* requires all its children to be untainted.

Efficiency Comparison

TreeKEM recent version uses **Commit framework**:

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- **TKEM**: Ignores the update following each Commit.
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- **TKEM_commit**: Each Commit contains a single operation.
  - **Less efficient** than TreeKEM.

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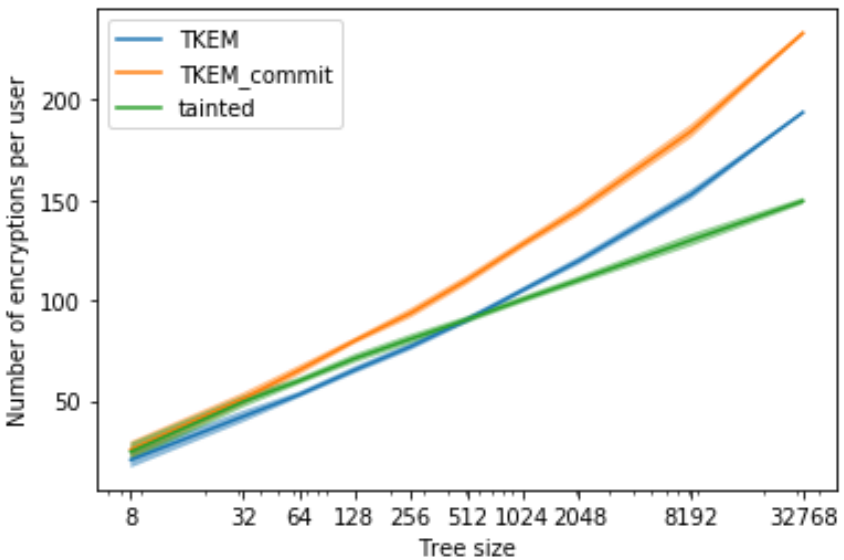

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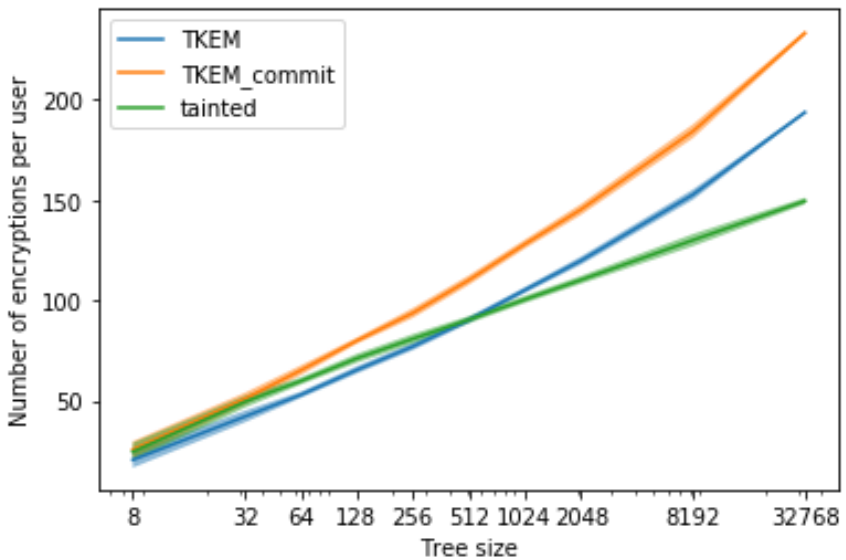

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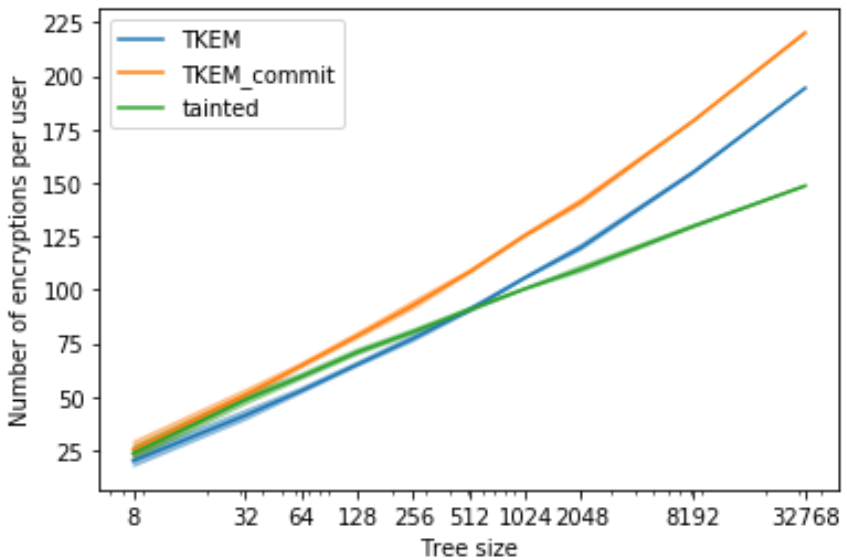

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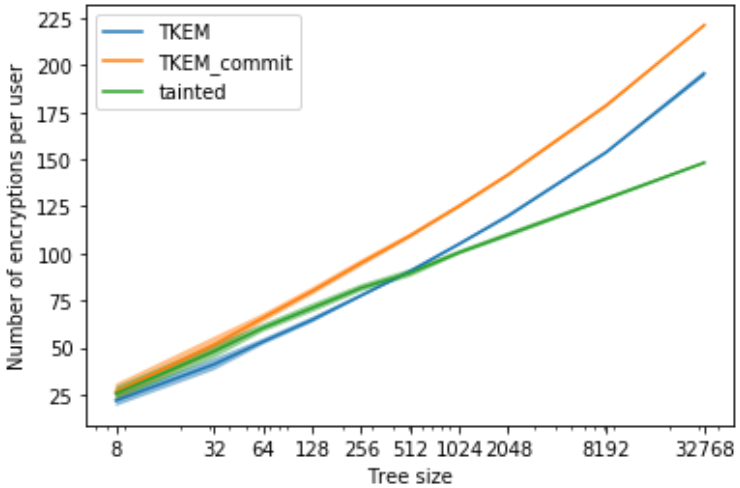

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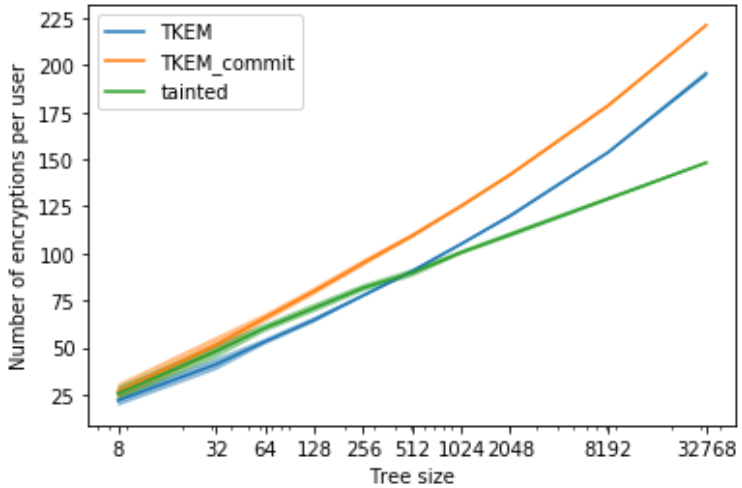

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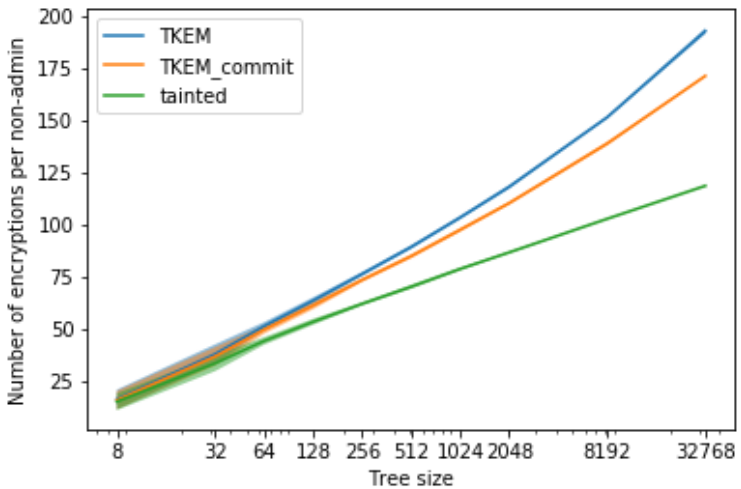
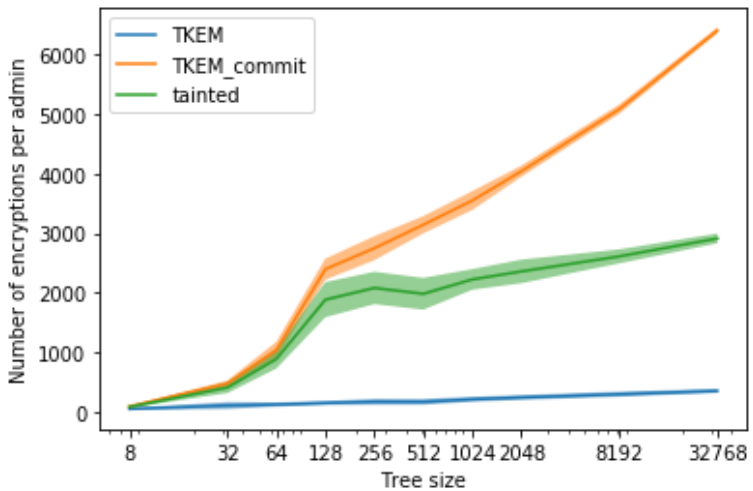


Cost for non-administrators



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- **"Partially" active**:
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  - Not allowed to craft messages.
- **Challenge**: Distinguish group key from random.
  - Challenge must not be trivial: define **safe** predicate

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Q - # of operations; n - # of users

Theorem (Standard Model)

Enc ϵ-*IND-CPA secure*, H ϵ-*pseudorandom*

$\Rightarrow$ *TTKEM* $\epsilon \cdot Q^{\log(n)}$-*CGKA-secure*.

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Open Problems:

- Can we extend security to malicious insiders?
- More efficient protocols? New approaches?
- Get better comparison using real world access patterns.

Thanks!