Keep the Dirt: Tainted TreeKEM, Adaptively and Actively Secure Continuous Group Key Agreement
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Introduction
This work focuses on improving the efficiency of existing Continuous Group Key Agreement (CGKA) protocols, underlying efficient secure group messaging. In particular, it builds on TreeKEM, the protocol by the IETF working group on Message Layer Security (MLS). We formalize and analyze a modification named Tainted TreeKEM (TTKEM).

Continuous Group Key Agreement (CGKA)
Interactive protocol allowing a group of $n$ users to agree on a common sequence of keys with the following characteristics:
- Dynamic membership: add and remove group members.
- Asynchronous: no assumptions on users online behaviour.
- Forward secret and Post-Compromise Secure.
Further, efficient key updates (logarithmic in $n$).

Efficiency
We are interested in the communication efficiency of equivalent protocol executions in TreeKEM and TTKEM. TreeKEM recent versions bundle several group operations into one. We compared TTKEM against two variants, one more and one less efficient than TreeKEM, resulting from different ways of bundling operations.

Ratchet trees
Basic data structure used by TreeKEM and TTKEM.
- Leaves: associated to users.
- Nodes: associated with PKE key-pairs.
- Edges: knowledge of source secret key implies knowledge of sink secret key.
  $\Rightarrow$ users know secrets keys on their path to the root.

Key update by party A
- chooses and encrypts fresh keys
- removes old keys

Only $\log(n)$ encryptions needed to communicate new keys to group.

Security
Adversarial Model.
We consider an adversary that:
- Can control protocol execution and corrupt users adaptively.
- Corrupts throughout time-windows:
  - leaks all user state, including randomness used while corrupted.
  - is "partially" active:
    - Full network control.
    - Not allowed to craft messages.
  - Wins if can distinguish group key from random.
- Exclude trivial challenge: define safe predicate.

Theorem 1 (Standard Model):
Enc $\epsilon$-IND-CPA secure, $H \epsilon$-pseudorandom $\Rightarrow$ TTKEM $\epsilon$-IND-CPA-secure.

Theorem 2 (Random Oracle Model):
Enc $\epsilon$-IND-CPA secure, $H$ random oracle $\Rightarrow$ TTKEM $\epsilon$-IND-CPA-secure.

where $Q$ - # of operations; $n$ - # of users.

Results Overview
- Formalized Tainted TreeKEM, a CGKA protocol using tainting instead of blanking.
- Efficiency simulations showing TTKEM is more efficient than TreeKEM for natural distributions.
- Security proofs for TTKEM both in standard model and ROM that extend to TreeKEM.
- First adaptive proof for any CGKA with polynomial loss.

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