Messaging Layer Security

The Beginning

Richard Barnes, Benjamin Beurdouche, Karthik Bhargavan,
Katriel Cohn-Gordon, Cas Cremers, Jon Millican,
Emad Omara, Eric Rescorla, Raphael Robert

RWC 2019, San Jose, CA

moz://a

Inria

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Objectives

Context

Lots of secure messaging apps

Some use similar protocols…

… some are quite different

… but all have similar challenges

Wildly different levels of analysis

Everyone maintaining their own libraries

Top-Level Goals

Detailed specifications for an **async** **group** **messaging security** protocol

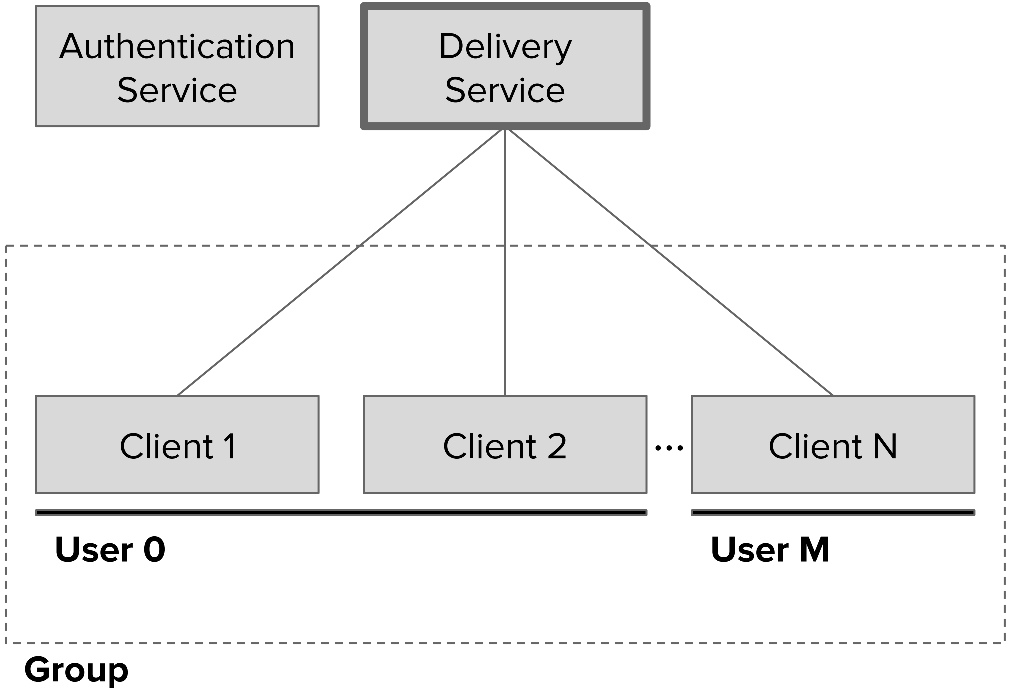
- **Async** - No two participants online at the same time
- **Group** - Support large, dynamic groups
- **Messaging security** - Modern security properties (FS / PCS)

Code that is reusable in multiple contexts...

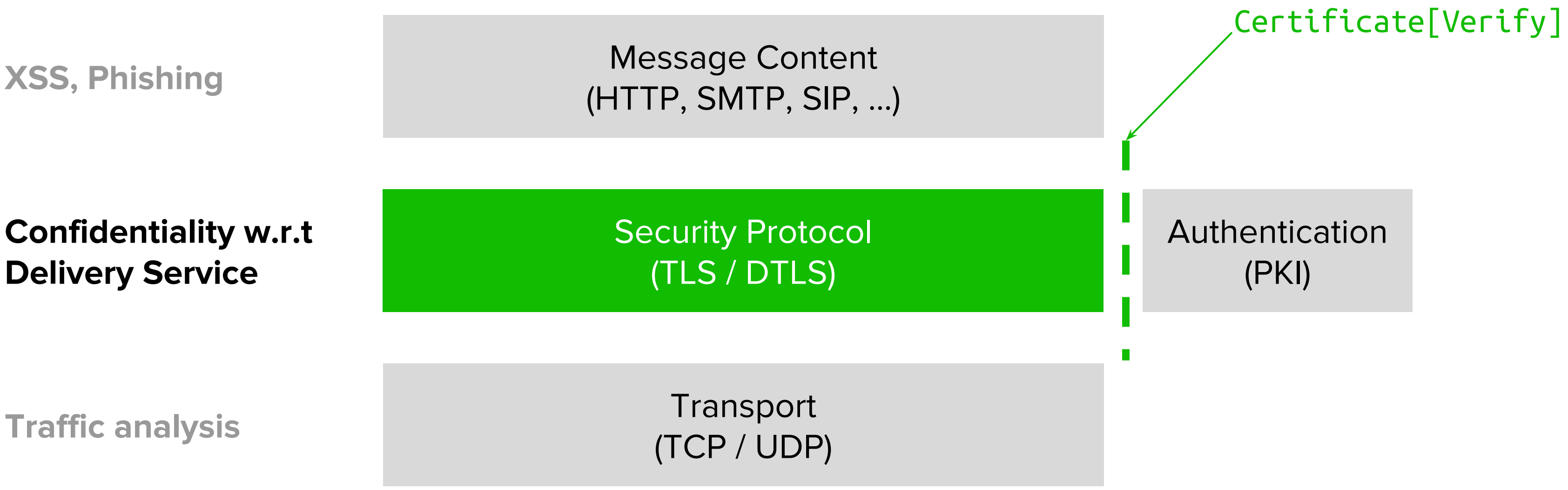
... and interoperable between different implementations

Robust, open security analysis and involvement from the academic community

Architecture



Scope (with analogy to TLS)



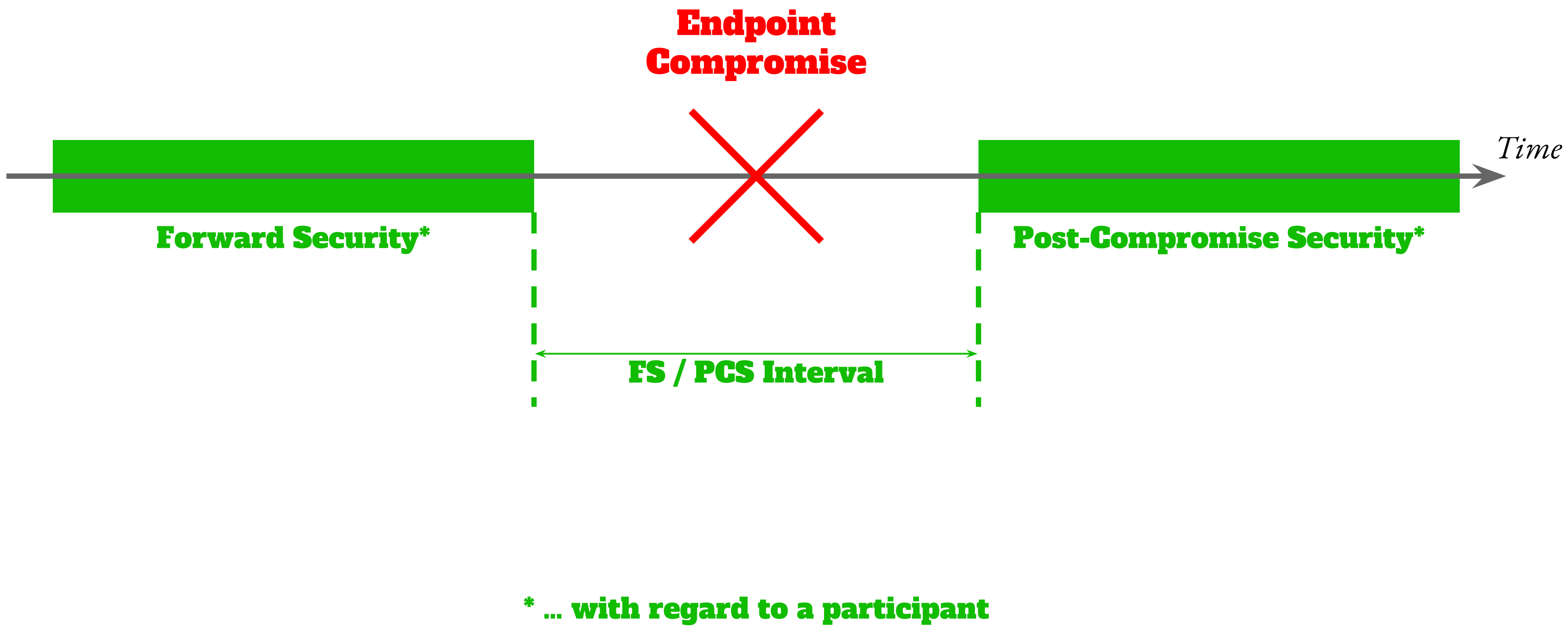
MLS vs. TLS

Lots of actors - 2 vs. 10^N

Long lived sessions - seconds vs. months

Lots of mobile devices involved

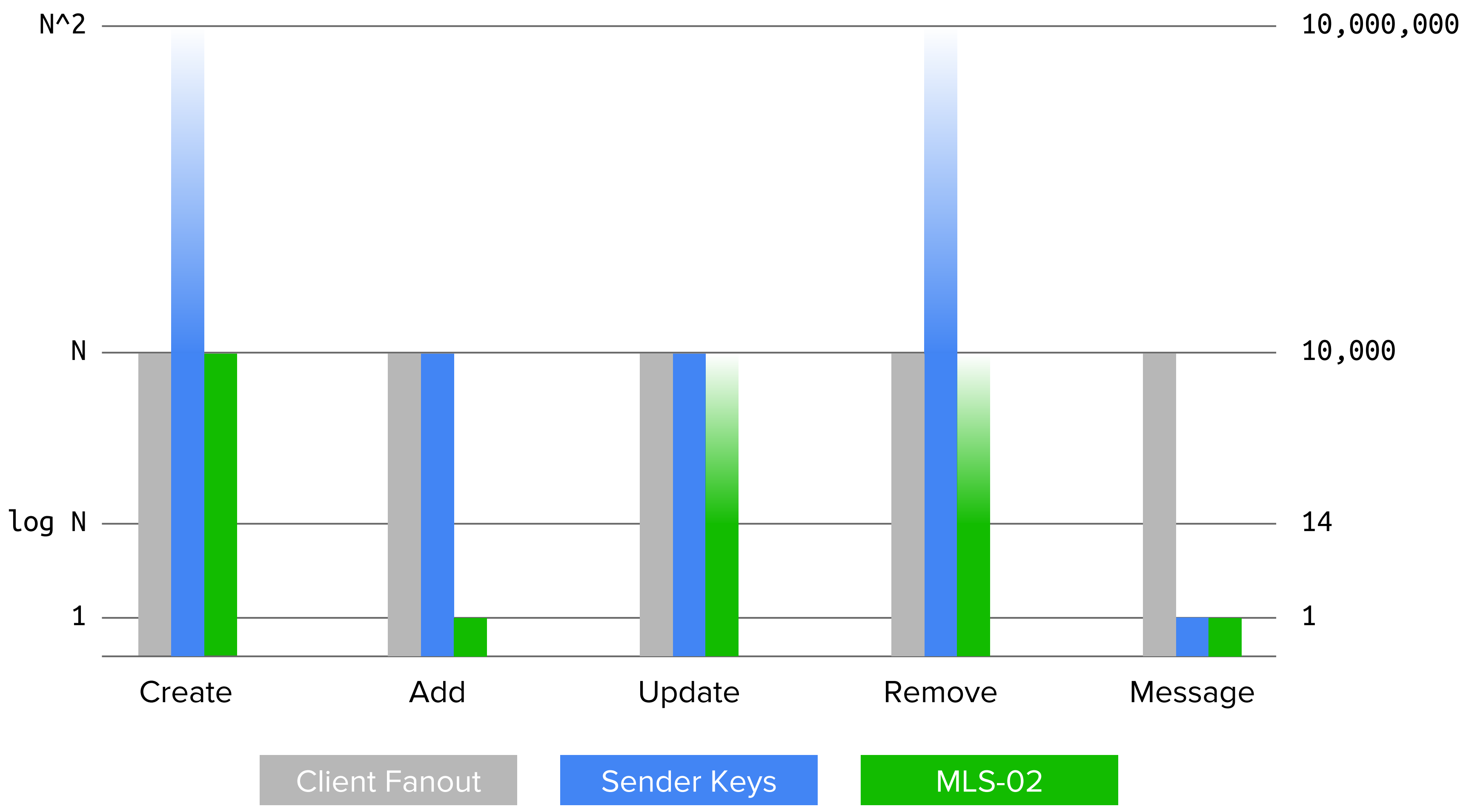
Significant probability that some member is compromised at some time in the life of the session


Endpoint
Compromise
Time
Forward Security*
Post-Compromise Security*
FS / PCS Interval
* ... with regard to a participant

Prior Art

mpOTR, (n+1)sec	No PCS
S/MIME, OpenPGP	Linear scaling, difficult to achieve PCS
Client fanout Signal, Proteus, iMessage, et al.	Linear scaling, but good async / PCS properties
Sender Keys WhatsApp, FB, OMEMO, Olm, et al.	Linear scaling, PCS possible but very expensive

Goal: FS/PCS with sub-linear scaling as much as possible


N^2
N
log N
1
10,000,000
10,000
14
1
Create
Add
Update
Remove
Message
Client Fanout
Sender Keys
MLS-02

History

Once upon an RWC...

RWC 2015
Millican and Barnes introduced

2016...
Barnes and Rescorla pondering specifications for messaging security
Millican, Cremers, Cohn-Gordon, et al. looking into tree-based schemes

RWC 2017
Hallway track conversations -- “Would a spec be useful?”

July 2017

On Ends-to-Ends Encryption:
Asynchronous Group Messaging with Strong Security Guarantees

https://eprint.iacr.org/2017/666.pdf

Say hi to your new Facebook friend, Jon.

Hey Jon! How are you?

Saw the tree-keying paper yesterday, looks like good work. Reaching out in case you're willing to answer some questions about notation 🙂

Hey Richard 🙂 I'm good thanks, how are you doing?

Sure I can try!

And thanks for reading it! 🙂

Things Start to Come Together

January 2018
MLS Workshop #3

November 2017
MLS Workshop #2

September 2017
MLS Workshop #1

March 2018
IETF MLS BoF

May 2018
IETF MLS WG officially formed

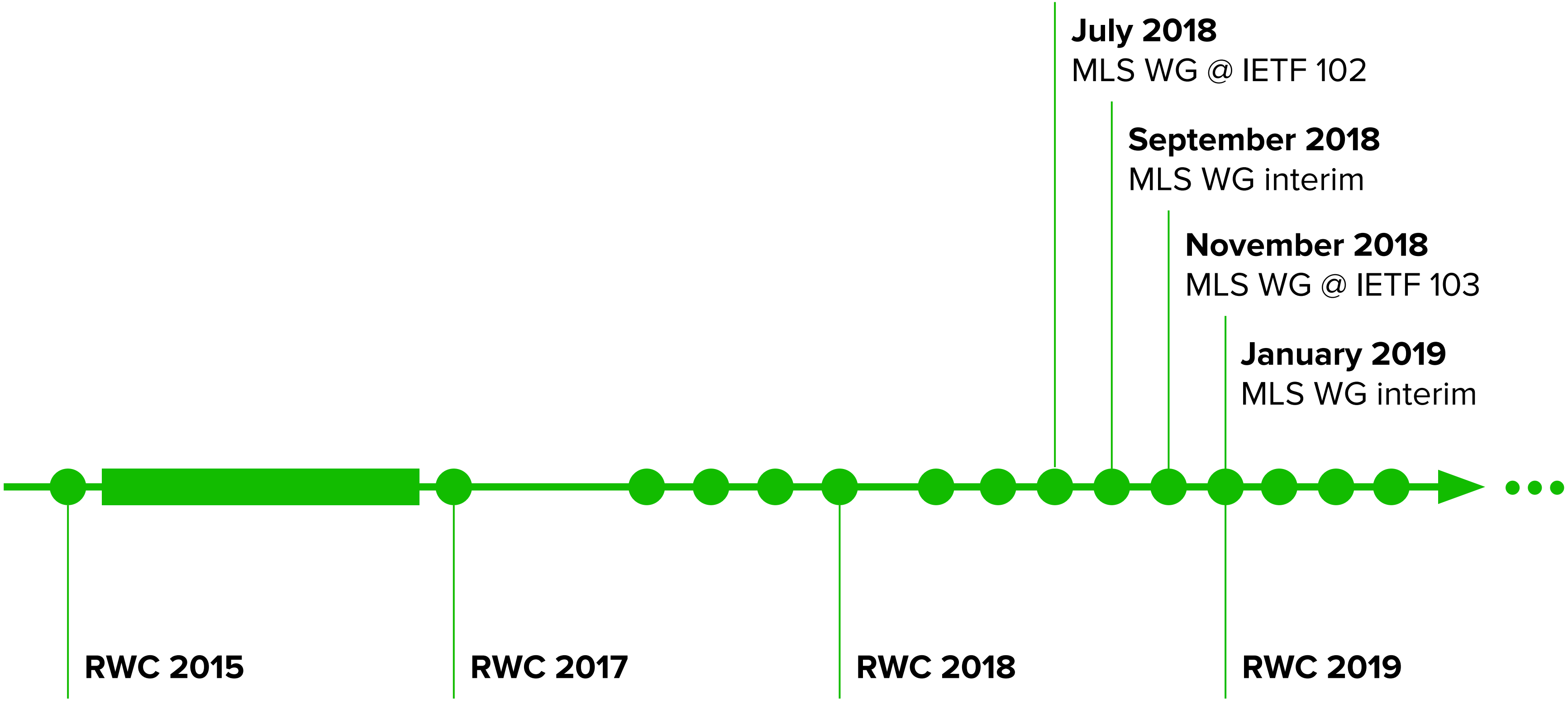
RWC 2015

RWC 2017

RWC 2018

RWC 2019

And Now, the Actual Work



Protocol

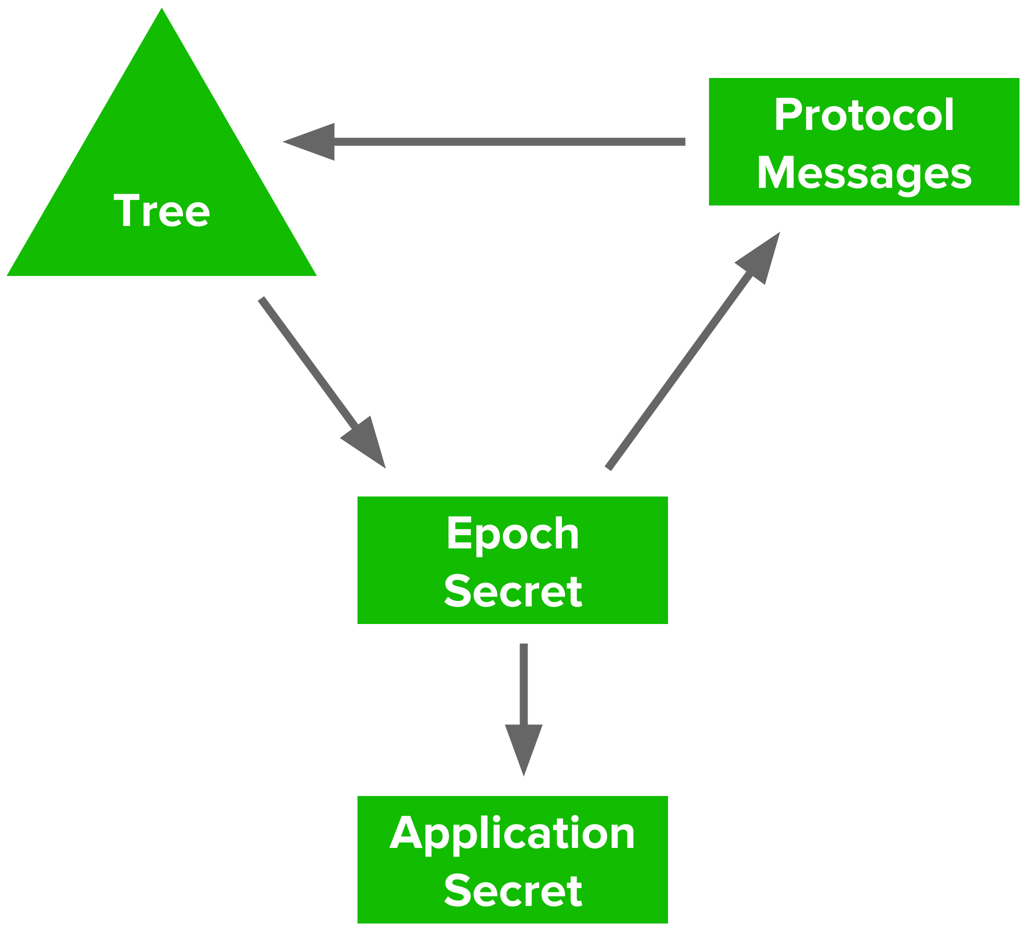

Tree
Protocol Messages
Epoch Secret
Application Secret

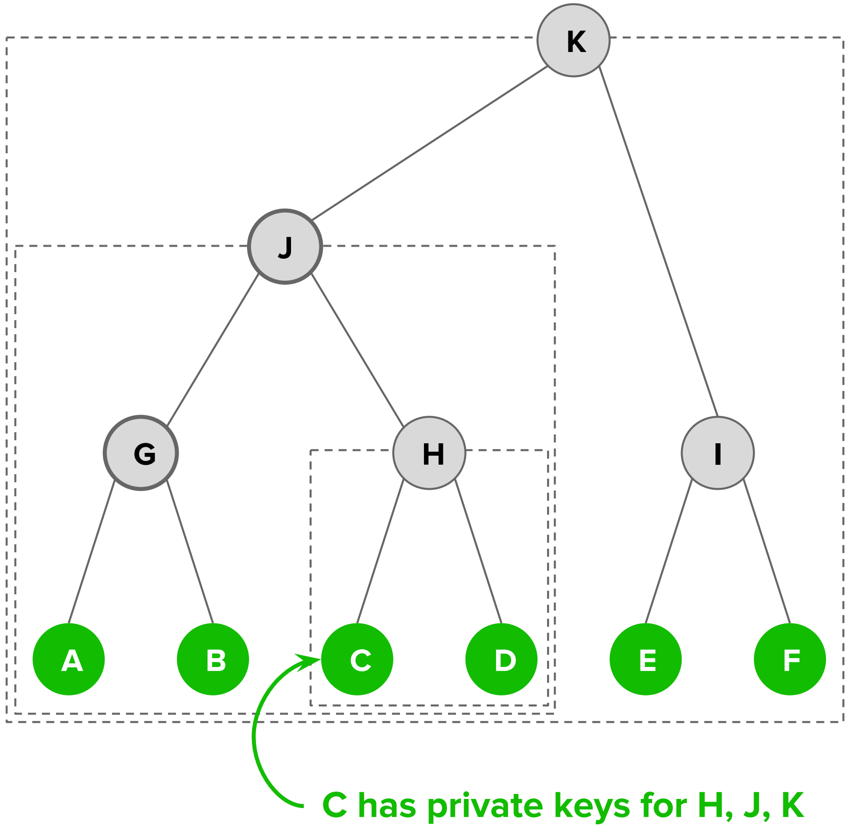
Photo Credit: Nathan Jones @ flickr

Trees of Keys

KE state of the group comprises a left-balanced binary tree of DH key pairs

Each member of the group occupies a leaf

<u>Tree invariant:</u> The private key for an intermediate node is known to a member iff the node is an ancestor of the member's leaf

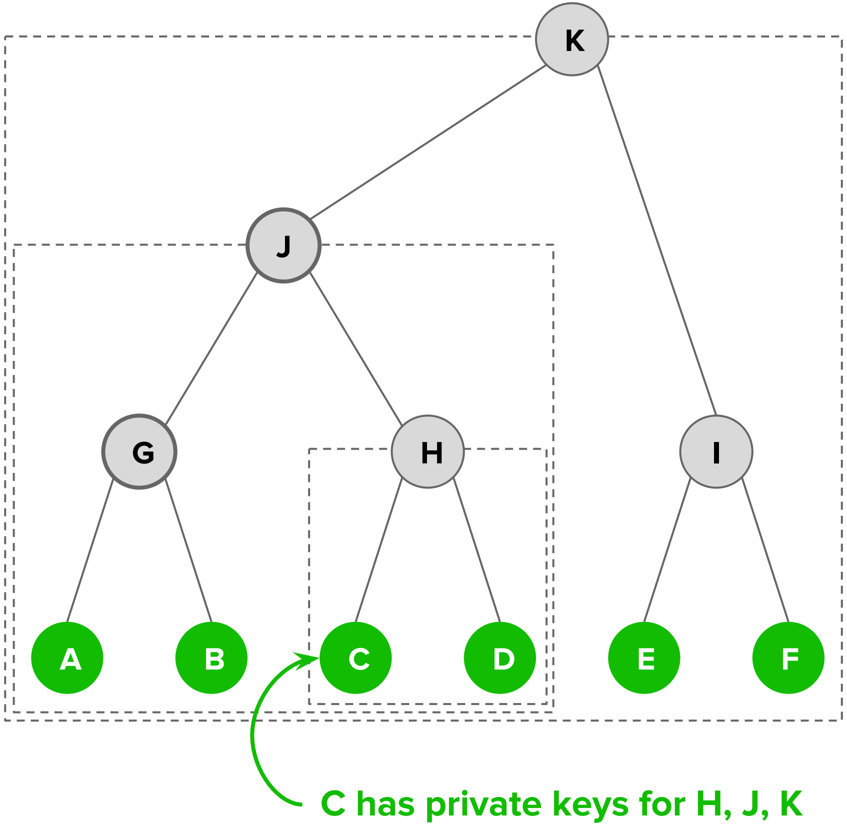


Trees of Keys

This has a couple of nice consequences:

> Intermediate nodes represent subgroups you can DH with / encrypt to
>
> Root private key is a secret shared by the members of the group at a given time

Protocol maintains this state through group operations (**Create**, **Add**, **Update**, **Remove**)



1st Try: Asynchronous Ratchet Trees (ART)

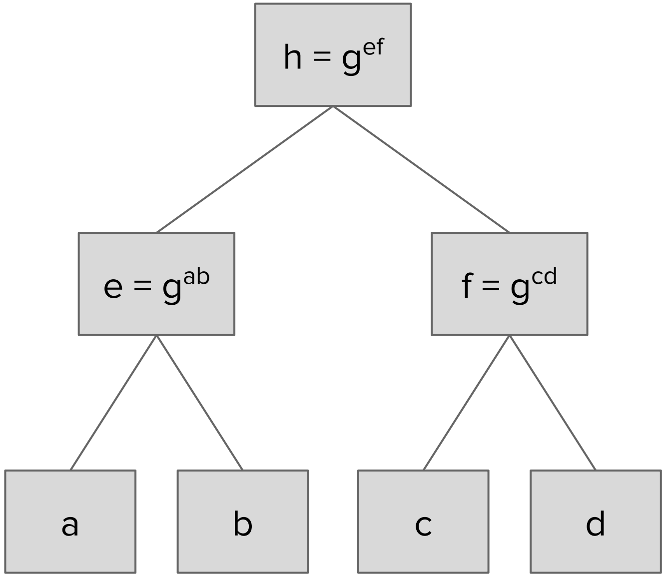
The key pair at an intermediate node is derived from a DH operation between its children

This enables log-depth **Update**:

Change the private key for a leaf

Re-derive the nodes up the tree

Add and **Remove** involve "double-join": A leaf private key held by two members



Cohn-Gordon, et al. ACM CCS 2017 https://eprint.iacr.org/2017/666.pdf

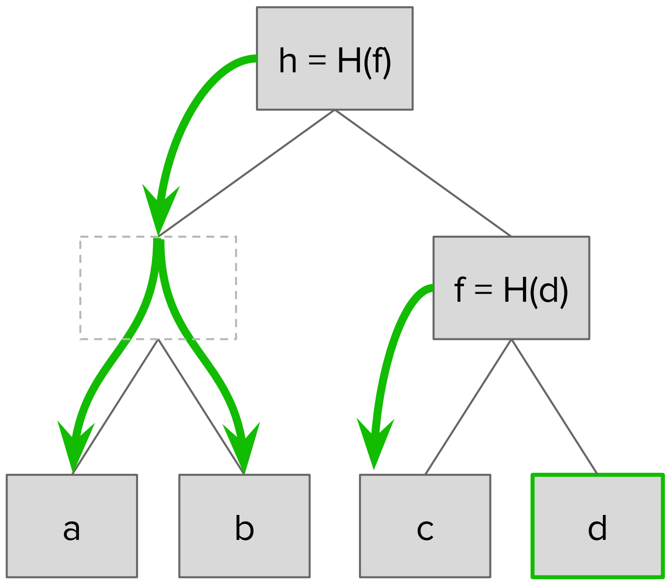
2nd Try: TreeKEM

Instead of doing DH to set intermediate nodes, when you change a leaf:

> Derive from hashes up the tree
> Encrypt the hash to the other child

This one operation does two things:

> Encrypt to all but the old
> Update the tree with the new



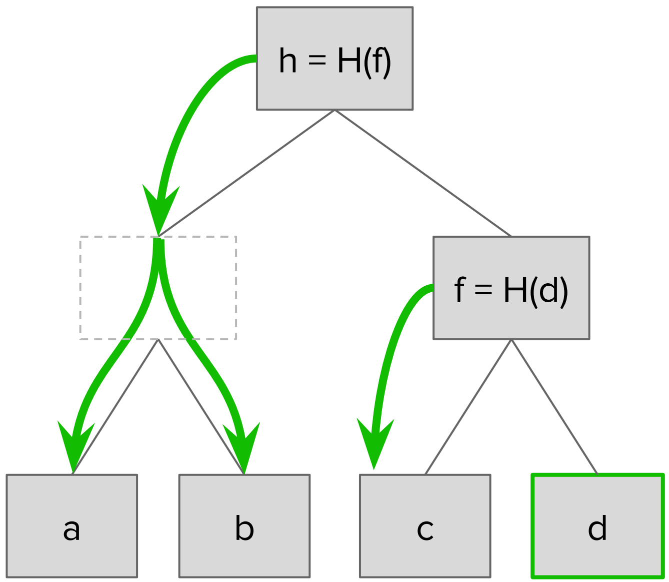
2nd Try: TreeKEM

Using encryption (vs. DH) enables blank nodes:

- **Add** and **Remove** without double join
- Constant-time **Add**

Other benefits vs. ART:

- Constant time for receivers (vs. log)
- More amenable to post-quantum



Protocol Messages Update The Tree

Add:

Add leaf to the tree

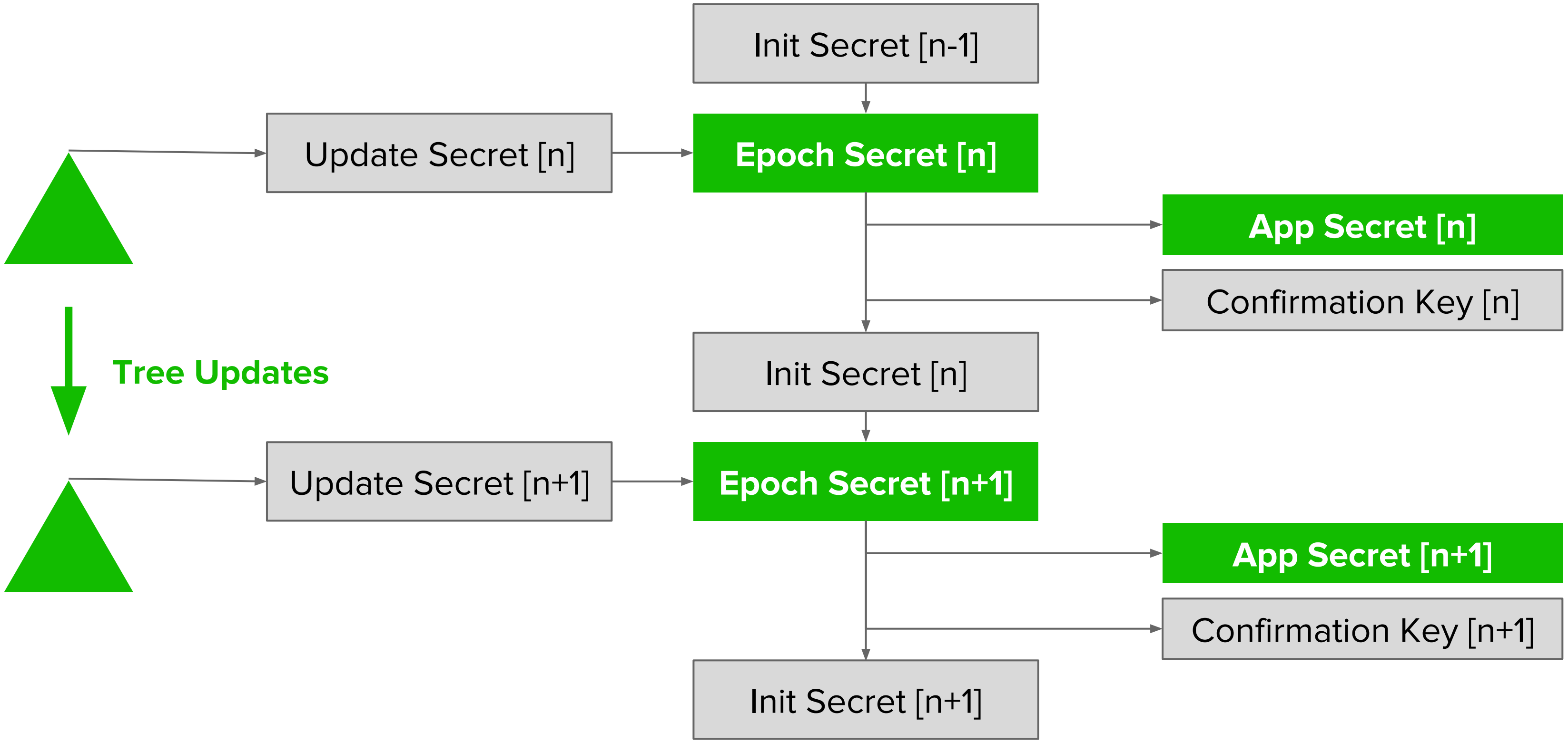
Group hashes forward

Encrypt secret to new joiner

Remove / Update:

Encrypt fresh entropy to everyone but the evicted participant

Key Schedule



Sign + MAC Authentication

```
struct {
  opaque group_id<0..255>;
  uint32 epoch;
  Credential roster<1..2^32-1>;
  PublicKey tree<1..2^32-1>;
  opaque transcript_hash<0..255>;
} GroupState;
```

Members of group agree on its state, including...

- Identities and public keys of members
- The public keys in the tree used for key exchange
- The transcript of Handshake messages (as a hash chain)

```
struct {
  uint32 prior_epoch;
  GroupOperation operation;
  uint32 signer_index;
  SignatureScheme algorithm;
  opaque signature<1..2^16-1>;
  opaque confirmation<0..255>;
} Handshake;
```

Messages that change the state include...

- Signature by key corresponding to roster
- MAC over transcript and state using key derived from updated group state

Analysis

Is It Actually Secure?

MLS tries to stay close to some things that have had security analysis, ART and TLS

ART paper has hybrid modelling: computational analysis of core and symbolic Tamarin proofs of other parts

Work in Progress: TreeKEM, Authentication, the whole system together

Some challenges:

- Complex threat model and security properties
- Dynamic groups of arbitrary size

Future Directions

Trade-Offs

Log-size KE messages

Constant-size app messages

⟹ Shared group state ⟹

Strict message ordering

State corruption by malicious insiders

Avoiding Double-Join

Constant-time Add

⟹ TreeKEM + Blank nodes ⟹

Linear-size state in clients

“Warm up time” after creation

Specification and Implementation

Architecture and specification still in progress, with several TODOs, e.g.:

- Efficiency of the core protocol
- Robustness w.r.t. malicious insiders
- User-initiated add
- Recovery from state loss
- ACK / NACK messages

Help wanted:

Reviews of the docs

Suggestions for how to improve them

Security analysis

Several implementations currently in progress:

- Melissa (Wire, Rust)
- mlspp (Cisco, C++)
- MLS* (Inria, F*)
- RefMLS (NYU Paris, JS)
- [redacted] (Google, C++)

Help wanted:

Other stacks

Pull requests to the above

Suggestions for interop testing

Messaging Layer Security

Architecture:	https://github.com/mlswg/mls-architecture https://protocol.messaginglayersecurity.rocks
Protocol:	https://github.com/mlswg/mls-protocol https://architecture.messaginglayersecurity.rocks
Code + Interop:	https://github.com/mlswg/mls-implementations
Discussion:	mls@ietf.org (archives)