Moving forward: Forward Secrecy in OpenPGP

Justus Winter <justus@sequoia-pgp.org>

DeltaX Freiburg, 2018-07-21

https://sequoia-pgp.org/talks/2018-08-moving-forward

Forward Secrecy

- compromise of long-term keys does not compromise session keys
  - not: Backward Secrecy aka Future Secrecy aka Post Compromise Security
- TLS (DHE-*), OTR, Signal, OMEMO
- in short:
  - use Diffie-Hellman key exchange to derive session keys
  - use long-term keys to authenticate the exchange

Forward Secrecy is a property of transport security

Data at rest vs. data in motion

- OpenPGP may also be used for backups, archives, etc.
- OpenPGP already supports this distinction!

Key Flags[1] to the rescue:

```
0x04 - This key may be used to encrypt communications.

0x08 - This key may be used to encrypt storage.
```

Compatibility

Sequoia	GnuPG	OpenKeychain	openpgp.js	rnp
✓	✗	✗	✗	✗

[1] Section 5.2.3.21 of RFC4880

Approximating Forward Secrecy I

- suggested by Brown et al in 2001[2]
- use short-lived encryption subkeys
- generate and publish in advance
- trivial to implement, requires no changes to peers

```
% gpg -k futura
pub   ed25519 2018-06-11 [SC] [expires: 2019-06-10]
      D2784F6DDEB59AB4162CCD3E0F08F2796B0B71E2
uid           [ unknown] Futura Proofa <futura@example.org>
[...]
sub   cv25519 2018-07-23 [E] [expires: 2018-07-30]
sub   cv25519 2018-07-16 [E] [expires: 2018-07-23]
sub   cv25519 2018-07-09 [E] [expires: 2018-07-16]
```

[2] https://tools.ietf.org/html/draft-brown-pgp-pfs-03

Approximating Forward Secrecy II

- example:
  - encryption keys valid for a week
  - publish half a year worth of keys
- cons:
  - all messages sent in a week are encrypted using the same key
  - generating keys in advance is a window for compromise
- pros:
  - good backwards compatibility
  - way better than the status quo

Compatibility

Sequoia	GnuPG	OpenKeychain	openpgp.js	rnp
✓	✓	✓	✓	✗

Interludum: Multi-device support

OpenPGP lacks a convincing story for multi-device support. Two options[3]:

1. sharing decryption-capable keys across devices
   - + hides number of devices
   - – requires synchronization between co-agents
2. distinct per-device decryption-capable keys
   - + requires synchronization only at setup
   - ± requires synchronization with remote peers
   - + still possible to hide number of devices by sharing
   - – requires minor modifications
   - – size of the certificate
   - – complexity

p≡p and Autocrypt synchronize using hidden mails:

- OpenPGP is transport protocol independent
- how does that work in practice?

[3] dkg's post to the MLS list

Simple per-device encryption keys

```
% gpg -k two
pub   ed25519 2018-06-08 [SC] [expires: 2019-06-07]
      2B7757D8AF283468A0574699910E554478CCDE00
uid           [ unknown] Two Fish <two@example.org>
sub   cv25519 2018-06-08 [E] [expires: 2019-06-07]
sub   cv25519 2018-06-08 [E] [expires: 2019-06-07]
```

Compatibility

Sequoia	GnuPG	OpenKeychain	openpgp.js	rnp
✓	✗	✓	✗	✗

Certification-capable subkeys

- short-lived encryption subkeys require recurrent synchronization
- our proposal[4]:

- use a set of keys per device:
  - a certification subkey: to issue their own subkeys
  - a signing subkey
  - n encryption subkeys
- use e.g. a QR-code containing an encrypted key and a binding signature to provision a new device
- requires clarification in the RFC, minor changes in implementations

Compatibility

Sequoia	GnuPG	OpenKeychain	openpgp.js	rnp
✗	✗	✗	✗	✓!?!

[4] Post to openpgp@ietf.org

Per-device keys: Example

Example key

primary key [C]

- subkey [E_r]
- subkey [A]

- new key, maybe on a Gnuk

Per-device keys: Example

Example key

primary key [C]

- subkey [E_r]
- subkey [A]
- subkey [C]: "desktop"
  - subkey [S]
  - n subkeys [E_t]

- new key, maybe on a Gnuk
- commission desktop

Per-device keys: Example

Example key

primary key [C]

- subkey [E_r]
- subkey [A]
- subkey [C]: "desktop"
  - subkey [S]
  - n subkeys [E_t]
  - subkey [C]: "laptop"
    - subkey [S]
    - n subkeys [E_t]

- new key, maybe on a Gnuk
- commission desktop
- commission laptop from desktop

Per-device keys: Example

Example key

primary key [C]

- subkey [E_r]
- subkey [A]
- subkey [C]: "desktop"
  - subkey [S]
  - n subkeys [E_t]
  - subkey [C]: "laptop"
    - subkey [S]
    - n subkeys [E_t]
  - subkey [C]: "mobile phone"
    - subkey [S]
    - n subkeys [E_t]

- new key, maybe on a Gnuk
- commission desktop
- commission laptop from desktop
- commission phone from desktop

Per-device keys: Example

Example key

primary key [C]

- subkey [E_r]
- subkey [A]
- subkey [C]: "desktop"
  - subkey [S]
  - n subkeys [E_t]
  - subkey [C]: "laptop"
    - subkey [S]
    - n subkeys [E_t]
  - subkey [C]: "mobile phone"
    - subkey [S]
    - n subkeys [E_t]

- new key, maybe on a Gnuk
- commission desktop
- commission laptop from desktop
- commission phone from desktop
- decommissioning desktop recursively decommissions all devices

Per-device keys: Example

Example key

primary key [C]

- subkey [E_r]
- subkey [A]
- ~~subkey [C]: "desktop"~~
  - ~~subkey [S]~~
  - ~~n subkeys [E_t]~~

- desktop is decommissioned

Per-device keys: Example

Example key

primary key [C]

- subkey [E_r]
- subkey [A]
- ~~subkey [C]: "desktop"~~
  - ~~subkey [S]~~
  - ~~n subkeys [E_t]~~
- subkey [C]: "laptop"
  - subkey [S]
  - n subkeys [E_t]

- desktop is decommissioned
- commission laptop again from Gnuk

Per-device keys: Example

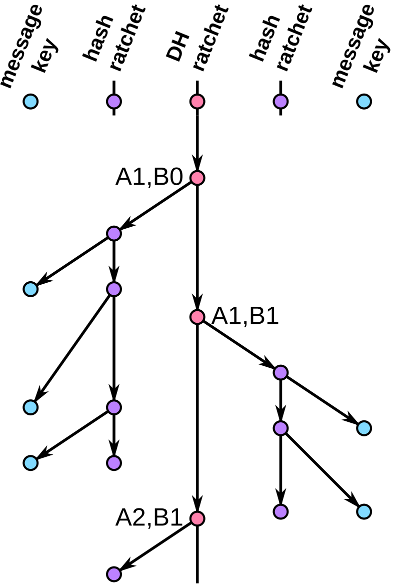
Example key

primary key [C]

- subkey [E_r]
- subkey [A]
- ~~subkey [C]: "desktop"~~
  - ~~subkey [S]~~
  - ~~n subkeys [E_t]~~
- subkey [C]: "laptop"
  - subkey [S]
  - n subkeys [E_t]
  - subkey [C]: "mobile phone"
    - subkey [S]
    - n subkeys [E_t]

- desktop is decommissioned
- commission laptop again from Gnuk
- commission phone from laptop

Signal's Double Ratchet



- DH and KDFs ratchets to derive session keys[a]
- also provides *Backward Secrecy*
- sending and receiving ratchets
- SK derived from KDF ratchet
- DH ratchet pingpongs
- per device keys
- one DR per device pair
- Signal and OMEMO use a server for initial DH keys

[a] Double Ratchet specification

Ditching the server

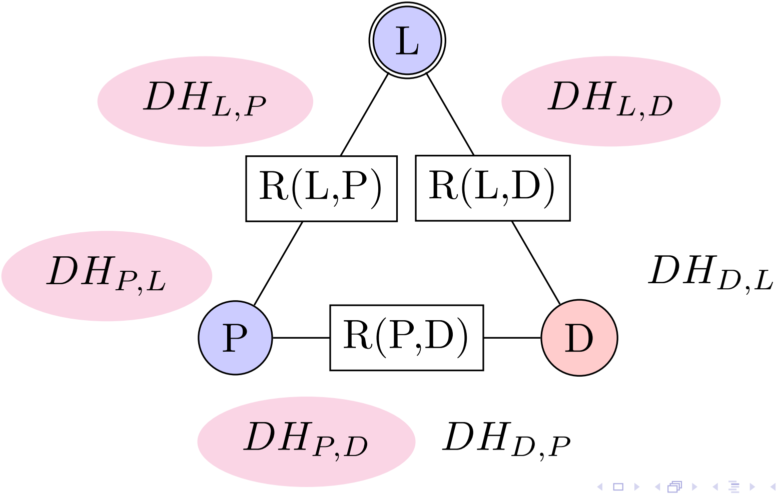
Initial message

- PKESK
- SEIP
  - OPS
  - Literal data
  - Signature
    +**DRInit**
  - MDC

- Signal/OMEMO:
  - generate n DH keys on devices, publish
  - initiator picks one from the server
  - nasty race condition in OMEMO
- our idea:
  - ditch the server
    - sacrifice protecting the first mail
    - include initialization in a traditional OpenPGP encrypted message
  - multiple devices
    - initiator generates all keys for one's own devices
    - encrypts these keys with the per-device encryption subkeys

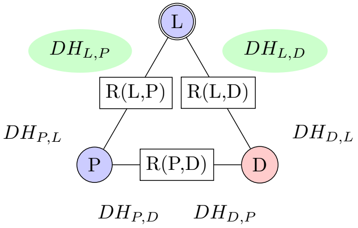
Double Ratchet initialization - setting

Alice has two devices, a laptop (L), and a phone (P). Bob has a desktop (D). Alice wants to send Bob a message from her laptop, they have not used the ratchet algorithm before. 3 ratchets: (L,D), (P,D), and (L,P).



Double Ratchet initialization I

- Alice generates four DH pairs. Two for the laptop, two for the phone.
- Alice sends a SEIP container with the message and the DH keys.

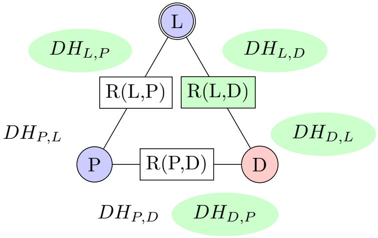


Alice$_L$ -> Bob

DRInit{pub: [$DH^{pub}_{L,D}$, $DH^{pub}_{P,D}$], sec: [$Enc_P(Sgn_L(DH_{P,D}, DH_{P,L}, DH^{pub}_{L,P}))$]}

Double Ratchet initialization II

- Bob generates two DH key pairs, initializes his ratchets.
- Bob sends his DH public key, and reflects all secrets.



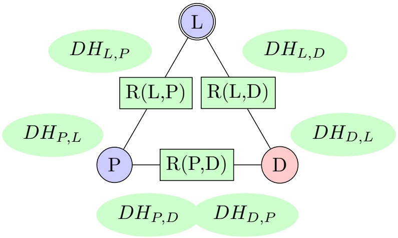
Bob -> Alice

DRESK{pub: $\mathrm{DH}^{\mathrm{pub}}_{\mathrm{D,L}}$, sec: $\mathrm{Enc}_{\mathrm{P}}(\mathrm{Sgn}_{\mathrm{L}}(\mathrm{DH}_{\mathrm{P,D}}, \mathrm{DH}_{\mathrm{P,L}}, \mathrm{DH}^{\mathrm{pub}}_{\mathrm{L,P}}))$, esk: ...}

DRESK{pub: $\mathrm{DH}^{\mathrm{pub}}_{\mathrm{D,P}}$, sec: $\mathrm{Enc}_{\mathrm{P}}(\mathrm{Sgn}_{\mathrm{L}}(\mathrm{DH}_{\mathrm{P,D}}, \mathrm{DH}_{\mathrm{P,L}}, \mathrm{DH}^{\mathrm{pub}}_{\mathrm{L,P}}))$, esk: ...}

Double Ratchet initialization III

- Alice's phone decrypts the initial DH key pairs generated on the desktop, and uses them to initialize her ratchets.
- The Double Ratchet algorithm initialization is now complete.
- To send more messages, she advances her two phone ratchets by creating two new DH pairs.



Alice$_P$ -> Bob

DRESK{pub: $DH'^{pub}_{P,D}$, sec: $\emptyset$, esk: $Cipher_{R(P,D)}(SK)$, PN, N_s}
DRESK{pub: $DH'^{pub}_{P,L}$, sec: $\emptyset$, esk: $Cipher_{R(P,L)}(SK)$, PN, N_s}

Double Ratchet in OpenPGP

What is needed to implement Forward Secrecy using the Double Ratchet algorithm?

- per-device keys
- two new packets, DRInit and DRESK
- keeping a lot of state in implementations

Juicy, but tricky. So let's go for Brown's short-lived encryption subkeys version first!

Ask questions! Get involved! Let's get Forward Secrecy into OpenPGP!

~~Checkout our repository of weird~~ keys[5].

[5] https://gitlab.com/sequoia-pgp/weird-keys

Bonus: Long-term Storage

Users expect to be able to read past mails. Two options:

- store session keys
  - we (Sequoia) want to do that anyway for speed
  - compromise of session key store compromises messages
  - need to purge session key if message is deleted
    - *deletability*!
  - requires one-time synchronization for new devices
- re-encrypt with long-term archive key
  - not desirable if messages are on a server (IMAP)

Bonus: Privacy-preserving keys{,ervers}

- critical for revocations/key renewals/new keys
- traditional keyservers are problematic
  - expose the social graph
  - expose names/email addresses
- idea: strip 3rd-party-certificates, uids

Compatibility

	Sequoia	GnuPG	OpenKeychain	openpgp.js	rnp
null-uid	✓	✓	✓	✓	✗
no-bound-uid	✓	✗	✗	✗	✗
no-uid	✓	✗	✗	✗	✗
direct-key	✗	✗	✗	?	✓