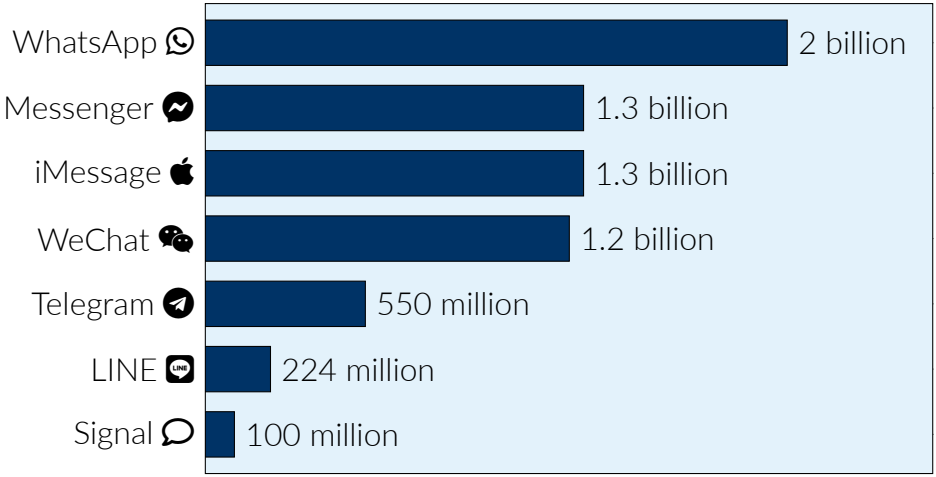
Secure Messaging in a Post-Quantum World

Most popular messaging apps



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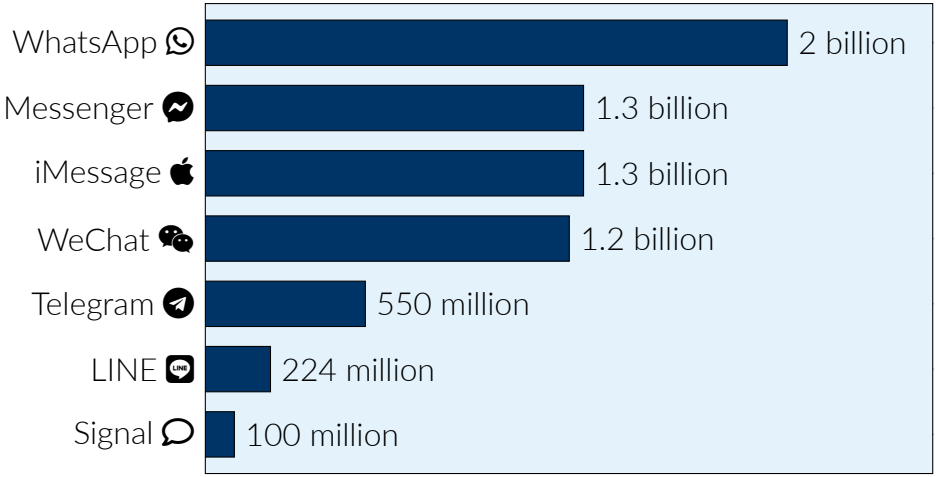


Most of these apps use specific protocols.

We focus on variations of the Signal protocol (,,).

Roadmap

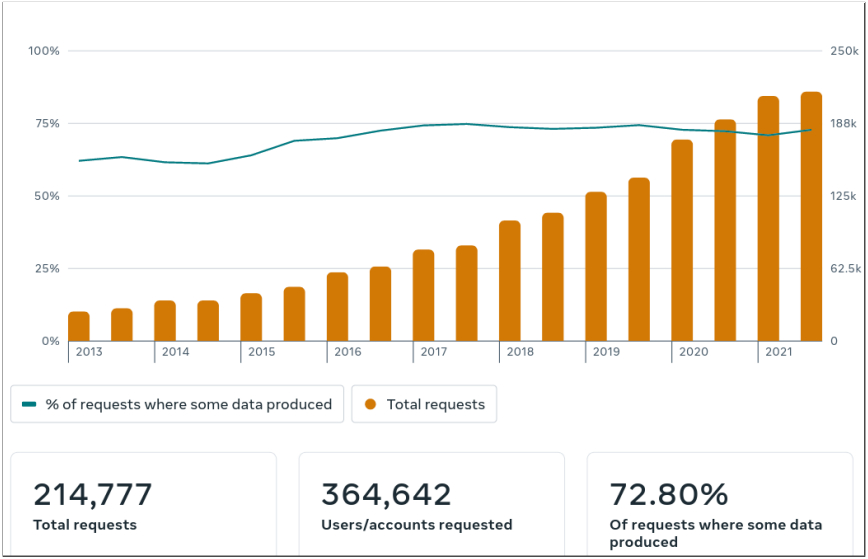
How do we obtain a secure messaging protocol that is simultaneously…

$$\underbrace{\text{post-quantum}}_{\text{Part I}} + \underbrace{\text{scalable}}_{\text{Part II}} + \underbrace{\text{metadata-hiding}}_{\text{Part III}} ?$$

(Post-Quantum) Security

Your personal data is always under attack

Meta's transparency report for Jul-Dec 2021



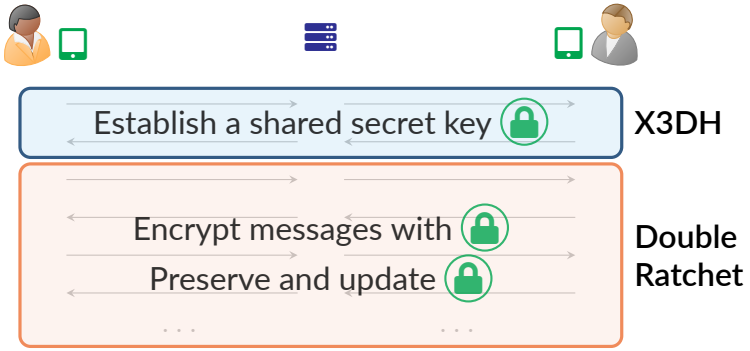
Legal means aren't the end of the story

Spyware sold off-the-shelf by companies and hackers

PEGASUS: THE NEW GLOBAL WEAPON FOR SILENCING JOURNALISTS

At least 180 journalists around the world have been selected as targets by clients of the cybersurveillance company NSO Group, according to a new Forbidden Stories investigation, published today.

The Signal protocol (two-users case)



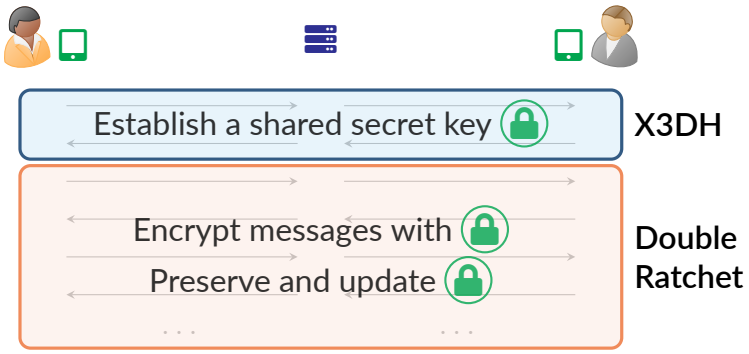
Two main threats

- State overreach
- Device compromise

Two main constraints

- Asynchrony
- Long sessions

The Signal protocol (two-users case)

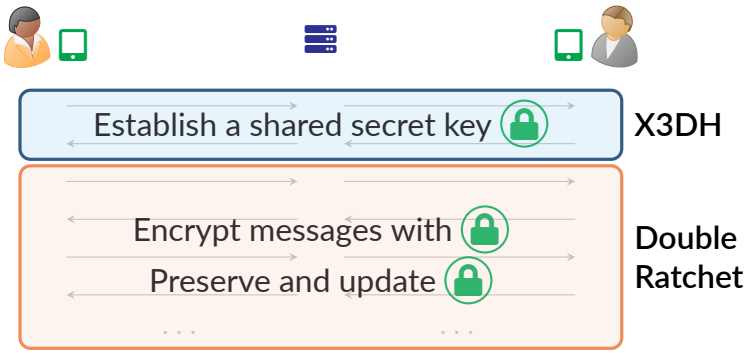


Pre-quantum world:

- **X3DH:**[1] Diffie-Hellman + XEdDSA + symmetric crypto (HKDF)
- **Double Ratchet:**[2] Diffie-Hellman + symmetric crypto (HKDF, HMAC, ...)

[1] https://signal.org/docs/specifications/x3dh/
[2] https://signal.org/docs/specifications/doubleratchet/

The Signal protocol (two-users case)

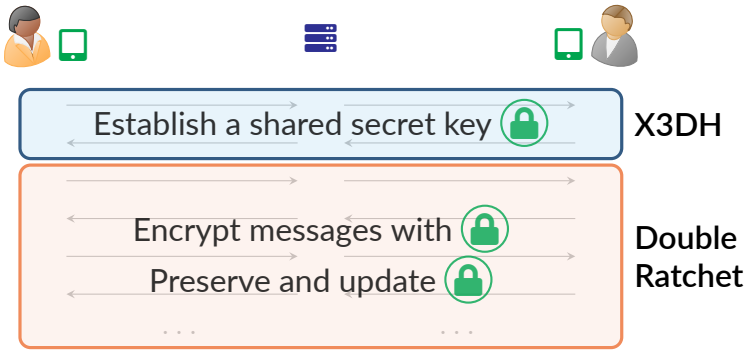


Post-quantum world:

→ **PQ X3DH:**[1] KEM + (ring) signatures + symmetric crypto

[1] Keitaro Hashimoto, Shuichi Katsumata, Kris Kwiatkowski, and Thomas Prest: *An Efficient and Generic Construction for Signal's Handshake (X3DH): Post-Quantum, State Leakage Secure, and Deniable*. PKC 2021 + Journal of Cryptology 2022.

The Signal protocol (two-users case)

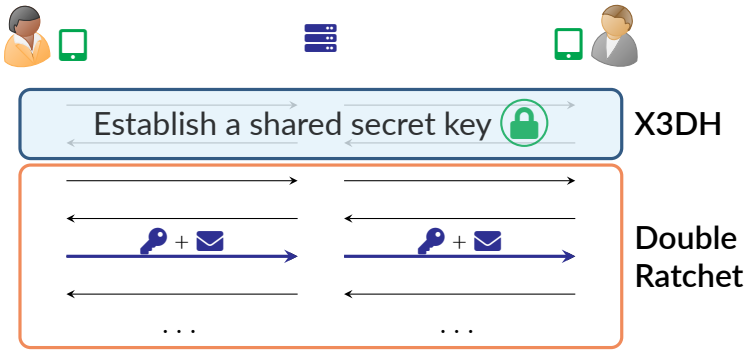


Post-quantum world:

- **PQ X3DH:** KEM + (ring) signatures + symmetric crypto
- **PQ Double Ratchet:**[1] KEM + symmetric crypto

[1] Joël Alwen, Sandro Coretti, and Yevgeniy Dodis: *The Double Ratchet: Security Notions, Proofs, and Modularization for the Signal Protocol.* EUROCRYPT 2019

Inside the PQ Double Ratchet



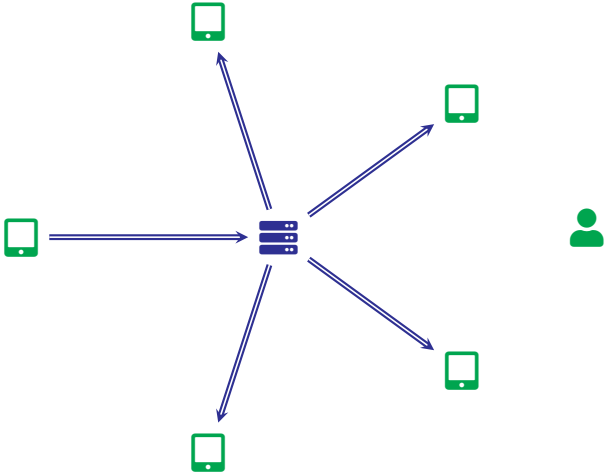
- Each user has a KEM keypair (only the encryption key is made public)
- Updating cryptographic material:
  - generates a new KEM keypair (including) and randomness
  - encrypts in a ciphertext using the encryption key of
  - incorporates into , and sends + to

  Both and are able to derive the updated

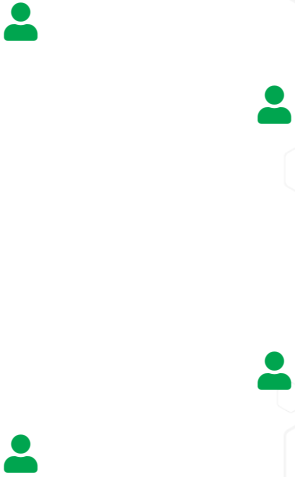
Scalable Group Messaging

Scaling Signal to groups – pairwise channels

Physical layer



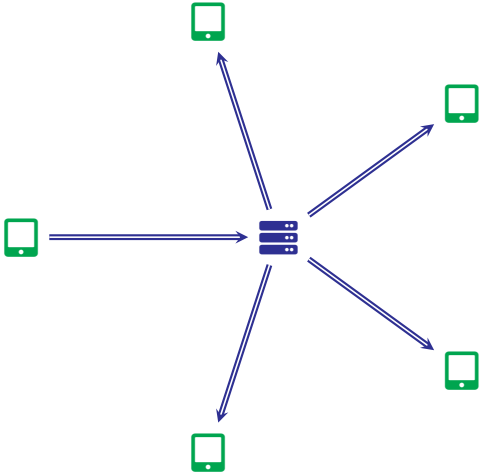
Insider view



Scaling Signal to groups – pairwise channels

PQ SHIELD

Physical layer



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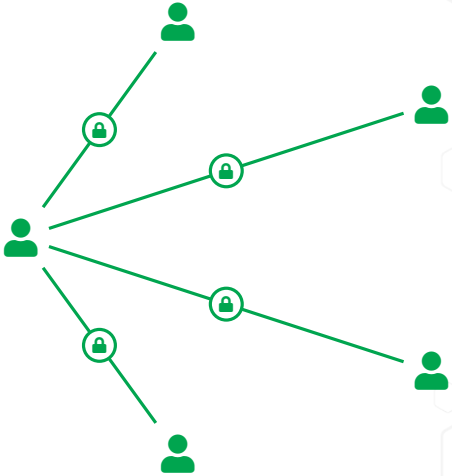

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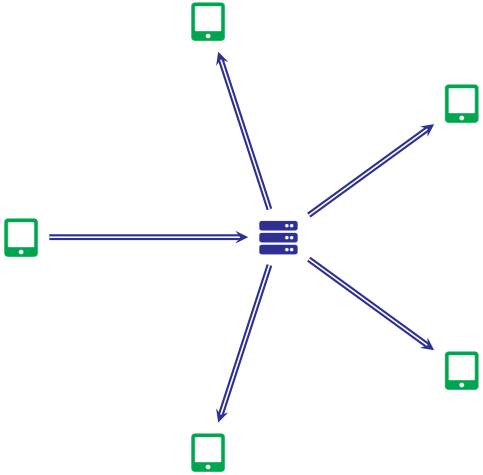

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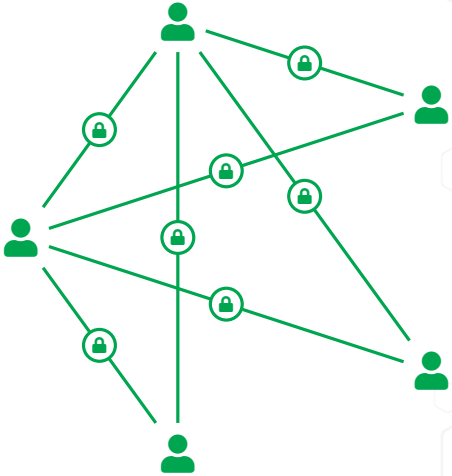

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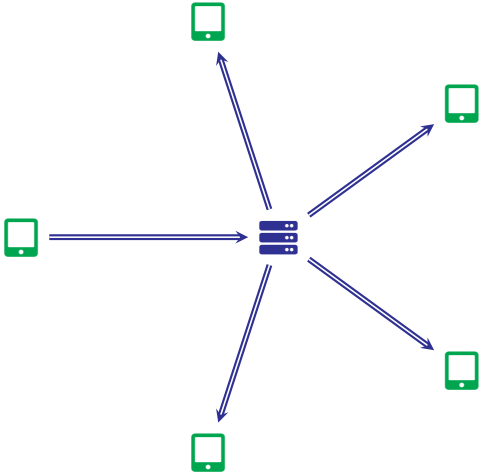

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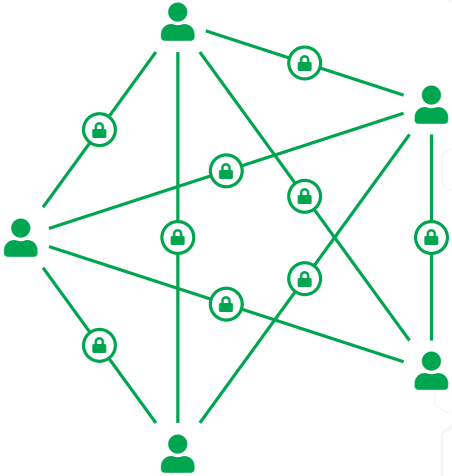

Scaling Signal to groups – pairwise channels

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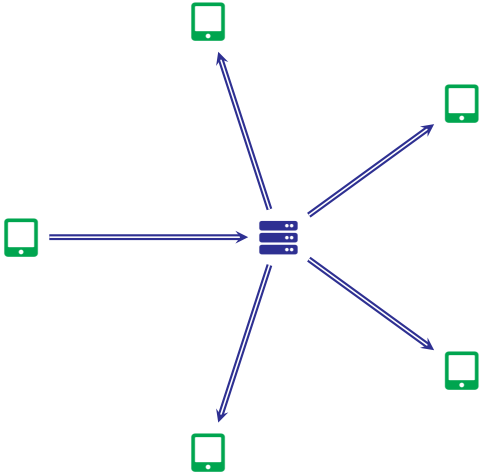

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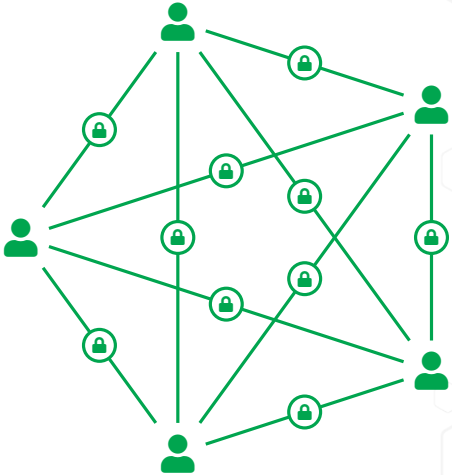

Scaling Signal to groups – pairwise channels

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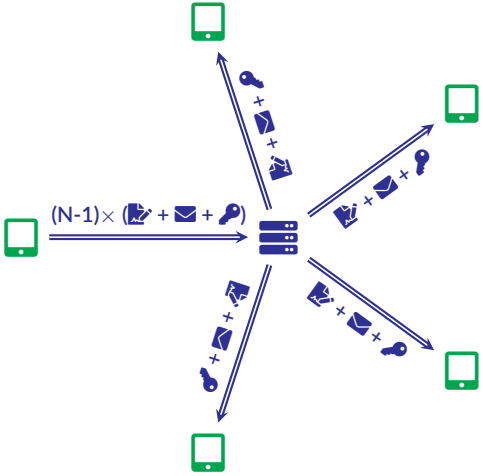

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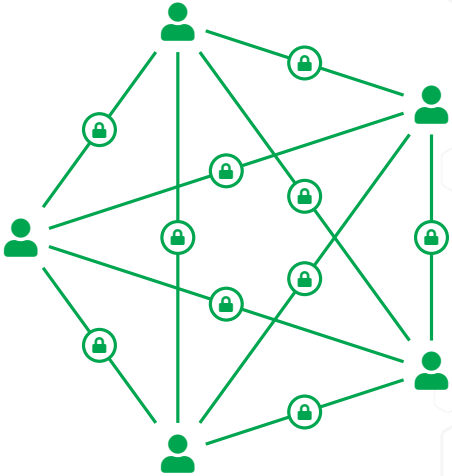
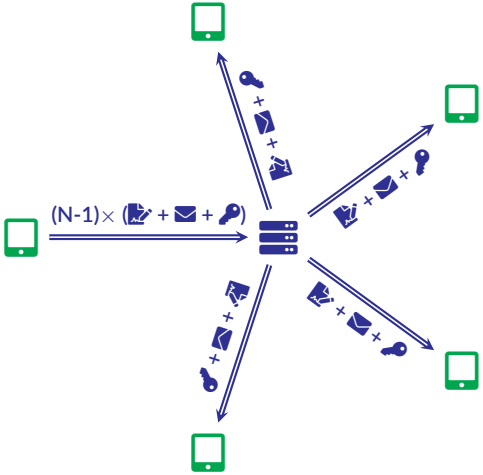


Cost of one update with $N = 256$, Kyber-512 and Dilithium-2:

1.2 Megabytes for the sender

Scaling Signal to groups – pairwise channels

Physical layer



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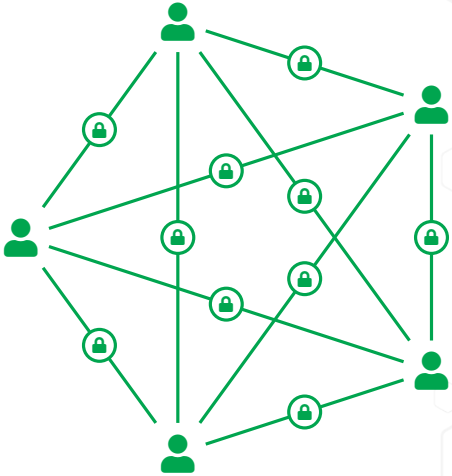
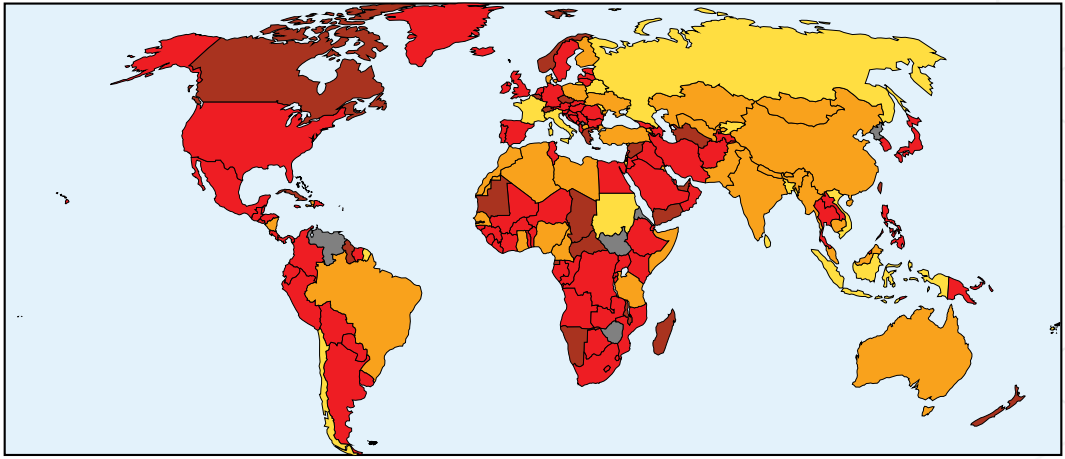


Sending a single picture of 100 Kilobytes with $N = 256$:

25.5 Megabytes for the sender

How much does 1 GB of mobile data cost?[1]

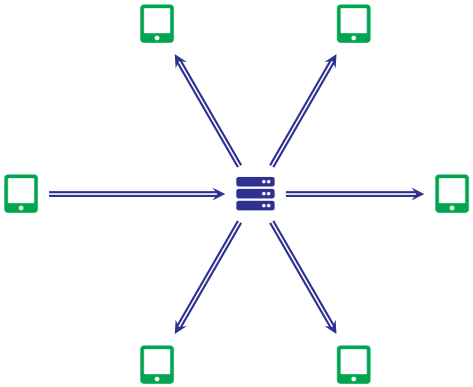


Median cost: ≤ $0.50 | ≤ $1.00 | ≤ $5.00 | ≥ $5.00

[1] https://www.cable.co.uk/mobiles/worldwide-data-pricing/

Our scalable protocol

- **One channel:** a single shared secret for the whole group[2]
- **One signature and one encryption key:** a single signature authenticates the encryption key and all the ciphertexts



[2] First proposed by Karthikeyan Bhargavan, Benjamin Beurdouche, Prasad Naldurg: *Formal Models and Verified Protocols for Group Messaging: Attacks and Proofs for IETF MLS*

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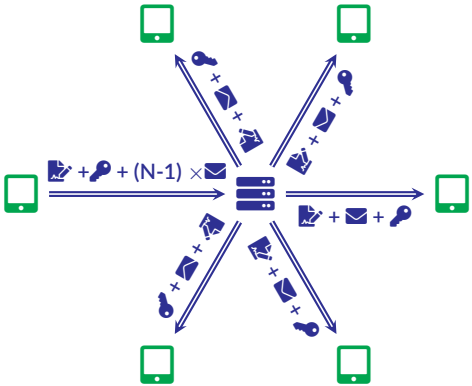

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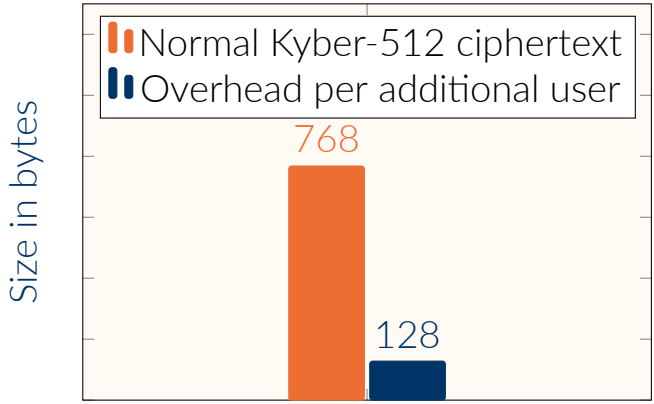
Multi-recipient public-key encryption

We can compress ciphertexts when encrypting the same message to *N* parties.
We exploit this when encrypting to the whole group.



Efficiency summary

Bandwidth costs in a group of N members

Scheme	**Message**	Update (upload)	Update (download)	**Update (total)**
Pairwise channels (Signal)	**O(N)**	O(N)	O(1)	**O(N)**
TreeKEM (MLS)	**O(1)**	O(log N)*	O(log N)*	**O(N log N)***
Our protocol§	**O(1)**	O(N)	O(1)	**O(N)**

*Best-case complexity

§Keitaro Hashimoto, Shuichi Katsumata, Eamonn Postlethwaite, Thomas Prest, and Bas Westerbaan: *A Concrete Treatment of Efficient Continuous Group Key Agreement via Multi-Recipient PKEs*. CCS 2021.

Protecting your Metadata

Metadata collection is systemic

PQ SHIELD

> “ Metadata, however, showing how a WhatsApp account was used and which numbers were contacting one another and when, can be tracked with a surveillance technology known as a pen-register. PenLink provides that tool as a service. ”

Forbes

CYBERSECURITY • EDITORS' PICK

Meet The Secretive Surveillance Wizards Helping The FBI And ICE Wiretap Facebook And Google Users

Thomas Brewster Forbes Staff

Associate editor at Forbes, covering cybercrime, privacy, security and surveillance.

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Feb 23, 2022, 01:53pm EST

2

A small Nebraska company is helping law enforcement around the world spy on users of Google, Facebook and other tech giants. A secretly recorded presentation to police reveals how deeply embedded in the U.S. surveillance machine PenLink has become.

Metadata collection, in more details

RollingStone

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POLITICS

FBI Document Says the Feds Can Get Your WhatsApp Data – in Real Time

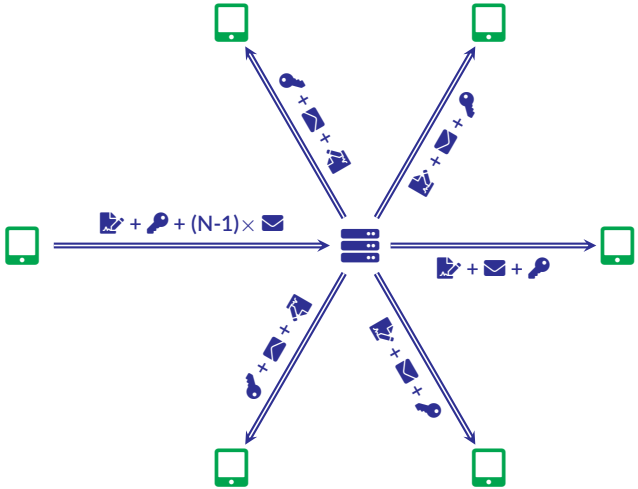
A previously unreported FBI document obtained by *Rolling Stone* reveals that "private" messaging apps WhatsApp and iMessage are deeply vulnerable to law-enforcement searches

BY ANDY KROLL

NOVEMBER 29, 2021

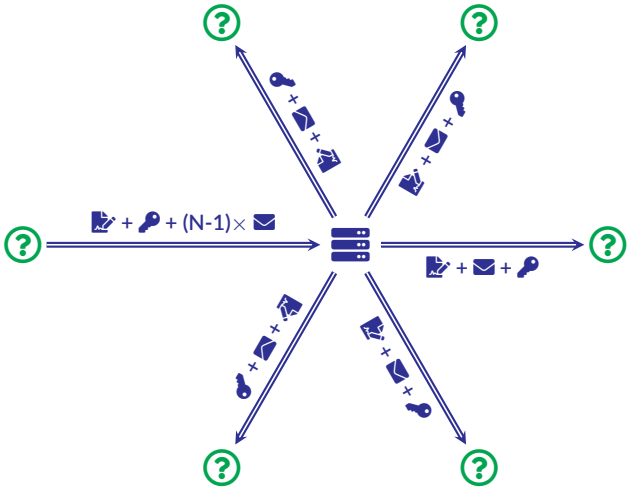
	iMessage	Line	Signal	Telegram	Threema	Viber	WeChat	WhatsApp
Subscriber data	☠	☠			☠	☠	☠	☠
Message sender, receiver data	☠	☠					☠	
IP address						☠	☠	
Date/time information	☠	☠	☠		☠	☠		☠
User contacts	☠	☠			☠	☠	☠	☠

Initial protocol
(🔑 = encryption key, ✉ = ciphertext, ✍ = signature)



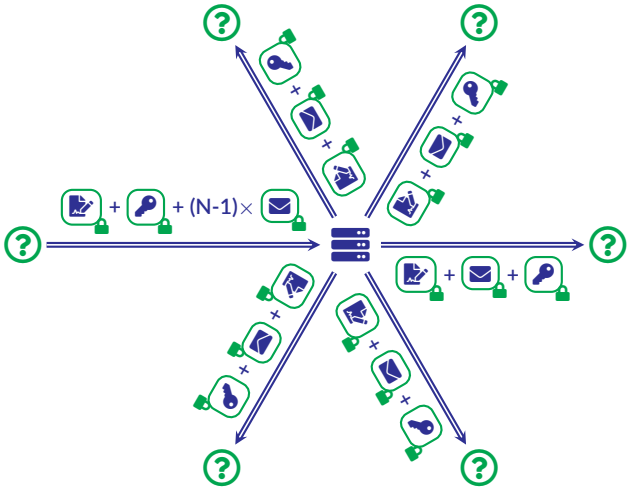
⚠ Messages are confidential, but not metadata (🖵)

Use client-anonymous authenticated channels



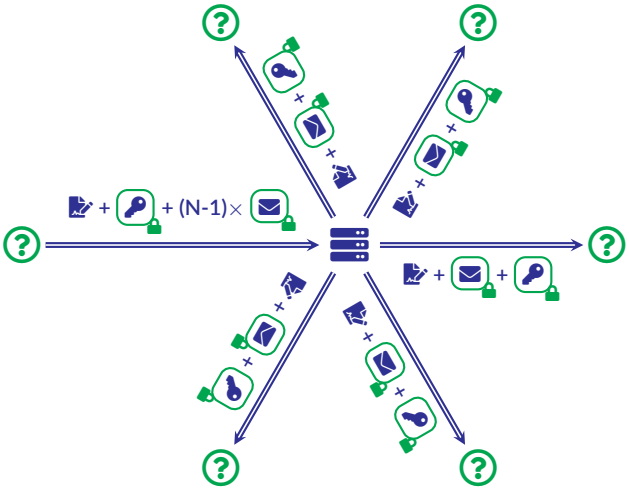
The packages , , leak the identities

OK, then let's also encrypt all the packages with



Now anyone can upload garbage messages to the group!

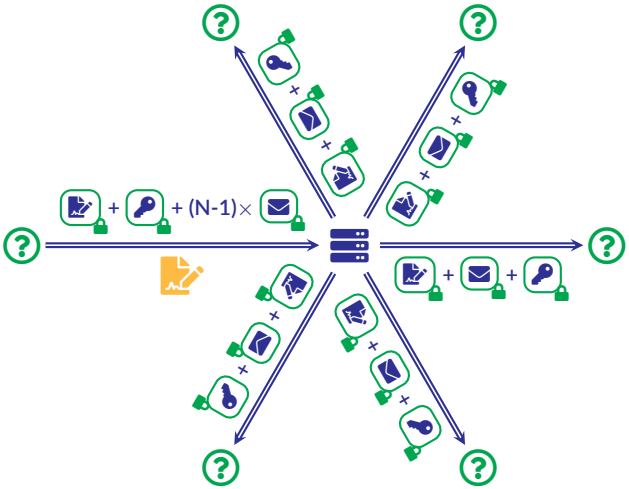
Let's encrypt all packages *except the signature*



But each signature is linked to its sender

Solution: derive a signature keypair (✎, 🔍) from 🔒‡

- The verification key 🔍 is public, but only users 👤 know the signing key ✎
- Group members can authenticate themselves anonymously



‡Keitaro Hashimoto, Shuichi Katsumata and Thomas Prest: *How to Hide MetaData in MLS-Like Secure Group Messaging: Simple, Modular, and Post-Quantum.* CCS 2022.

Conclusion

We show how to make secure messaging:

- Post-quantum
- Scalable
- Metadata-hiding

More information in our whitepaper

- https://pqshield.com/whitepapers/
- Also references the extensive body of work we build upon

Questions?