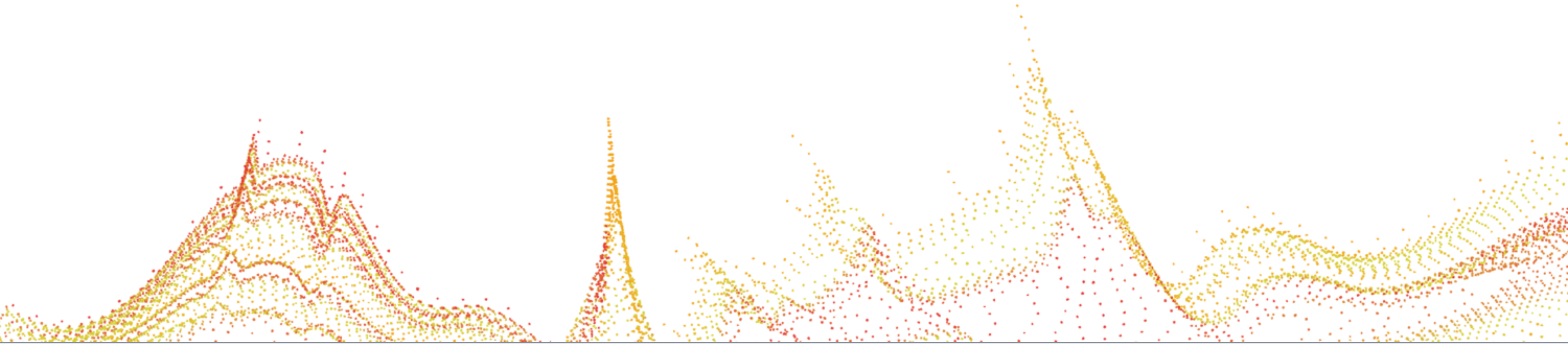
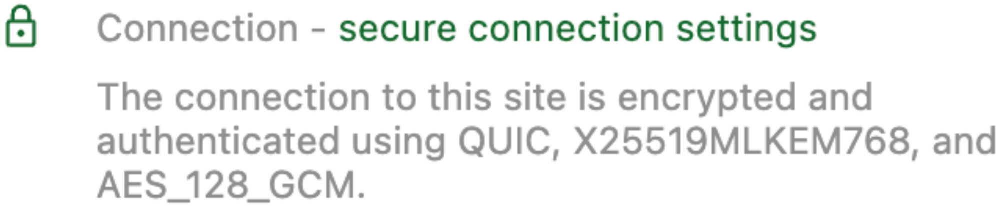
How are we going to afford post-quantum authentication?

Thom Wiggers



PQ is going great

Cloudflare, Google Chrome, Microsoft Edge, and Firefox deployed PQ key exchange in web browsing.



Connection - secure connection settings

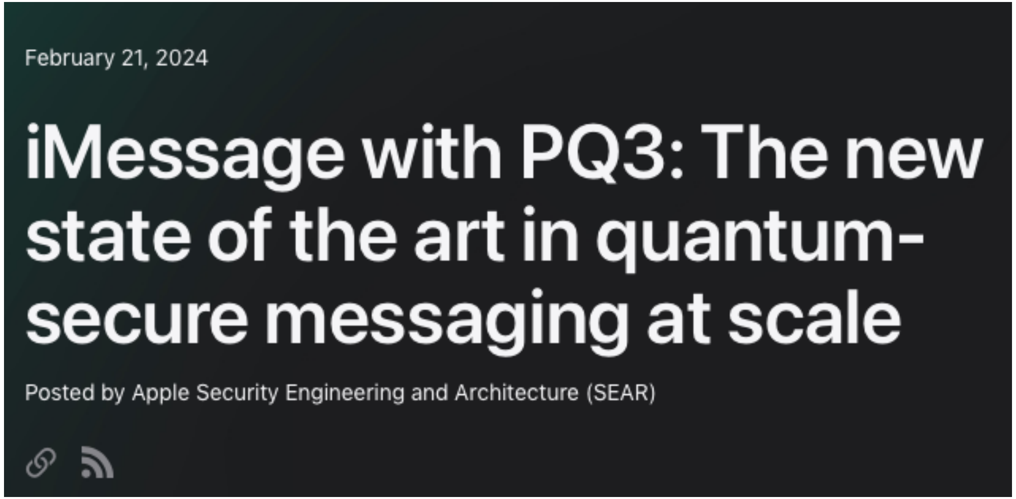
The connection to this site is encrypted and authenticated using QUIC, X25519MLKEM768, and AES_128_GCM.

PQ is going great

Signal and Apple deployed PQ key exchange in messaging

Quantum Resistance and the Signal Protocol

ehrenkret on 19 Sep 2023



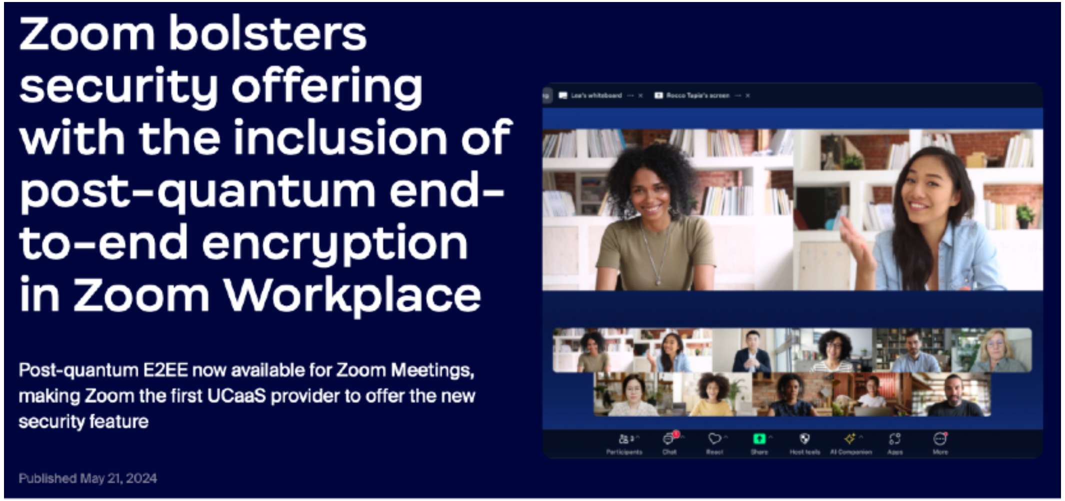
February 21, 2024

iMessage with PQ3: The new state of the art in quantum-secure messaging at scale

Posted by Apple Security Engineering and Architecture (SEAR)

PQ is going great

Zoom offers PQ key exchange in video calls



Zoom bolsters security offering with the inclusion of post-quantum end-to-end encryption in Zoom Workplace

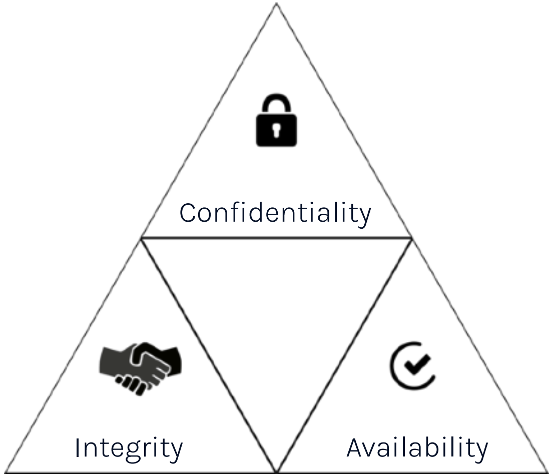
Post-quantum E2EE now available for Zoom Meetings, making Zoom the first UCaaS provider to offer the new security feature

Published May 21, 2024

What the headlines are not telling you

All of these examples: only PQ key exchange

Apple: “We will continue to assess the need for post-quantum authentication to thwart such attacks.”
Signal: “Further research in the area of post-quantum cryptography will be needed to fill in the remaining gaps.”
Cloudflare: “Over the coming years, we’ll be working with browsers to test the viability and performance impact of post-quantum authentication in TLS.”



Why the focus on PQ key exchange?

- Confidentiality is strongest link
  - Only needs to be updated in 1 spot: much easier
- ML-KEM is small-*ish* and very fast
- “Harvest-Now-Decrypt-Later” makes it urgent

We are right to focus on PQ key exchange first!

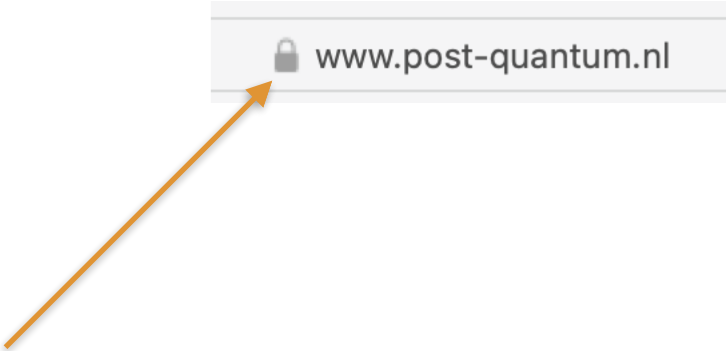
But PQ Authentication will be more complicated, take more effort, and more time.
We should start now.

More data = more slow

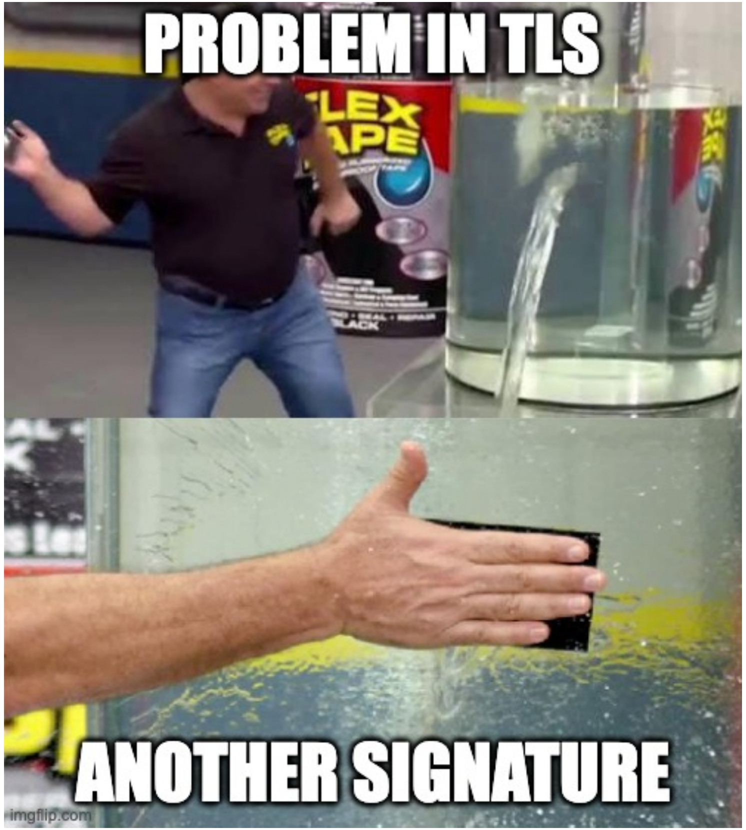
- Google reported that adding ML-KEM slows down TLS by 4%
- This only added 2kB to the client and server messages
- Google requires to stay under 10% slowdown
    - They estimate a <7 kB budget

Case study: TLS

- “The lock in the browser”
- Web browsers run on powerful devices
- Probably most-used cryptographic protocol
- If we can’t transition TLS, what can we?

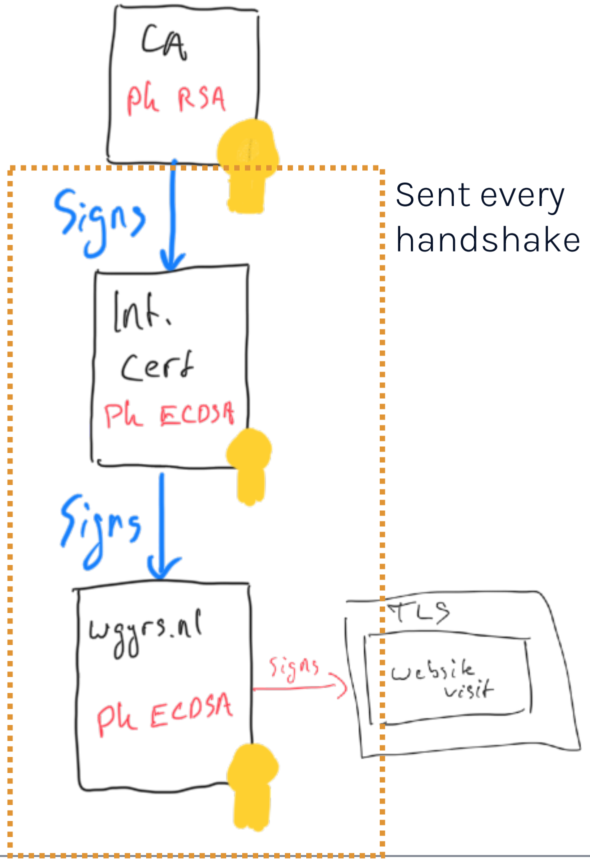


www.post-quantum.nl


PROBLEM IN TLS
FLEX TAPE
ANOTHER SIGNATURE
imgflip.com

Case study: TLS

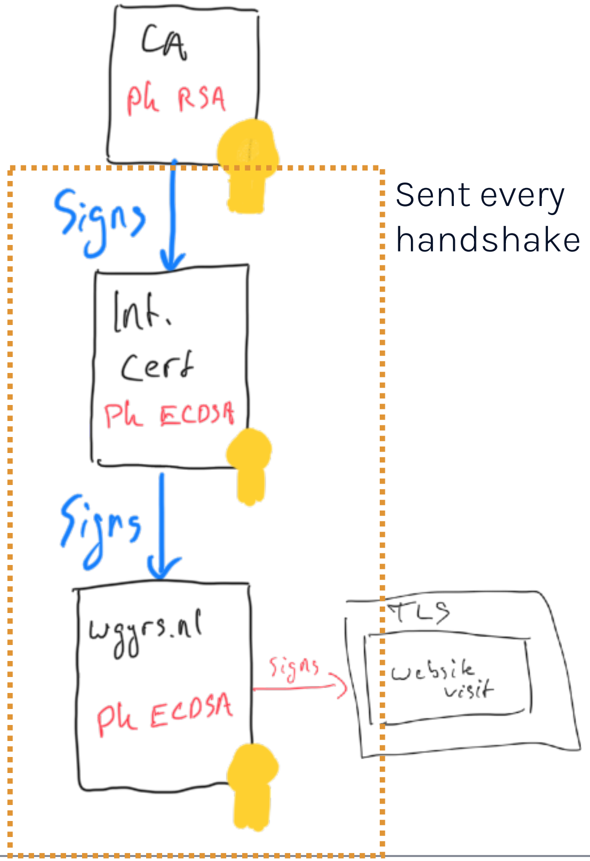
- TLS sends a lot of certificates every time
- These certificates contain further signatures for Certificate Transparency and certificate revocation
- Typical **web** TLS handshake:
  - handshake signature
  - leaf certificate:
    pk
    + signature by intermediate CA crt
    + OCSP staple
    + 3x SCT
  - intermediate CA certificate:
    pk + signature by root CA
  - root certificate (preinstalled)



Sent every handshake

The cost of PQ authentication

- An RSA public key + signature require ~0.5kB
- ML-DSA-44 requires 3732 bytes for the same
- This means that e.g. TLS overhead increases by up to ~18kB



Sent every handshake

Point of View: website operator

PQ key exchange:

- Solves Harvest-Now-Decrypt-Later
- Only need to update in 1 spot
- Well-tested now
- Adds ~2kB of data to handshake
- ~4% slowdown for most clients is costly but acceptable (src: Google)

PQ authentication:

- Will only protect after quantum apocalypse
- Requires updating certificate infra
- Dependencies on suppliers and ecosystem
- ~4% slowdown for ~2kB means big slowdown for ~18kB

“I’ll wait”

Hard to swallow pills
PQ AUTH IS GONNA BE HARD
54 543
WE CAN'T AFFORD WAITING
imgflip.com

“But what about the…

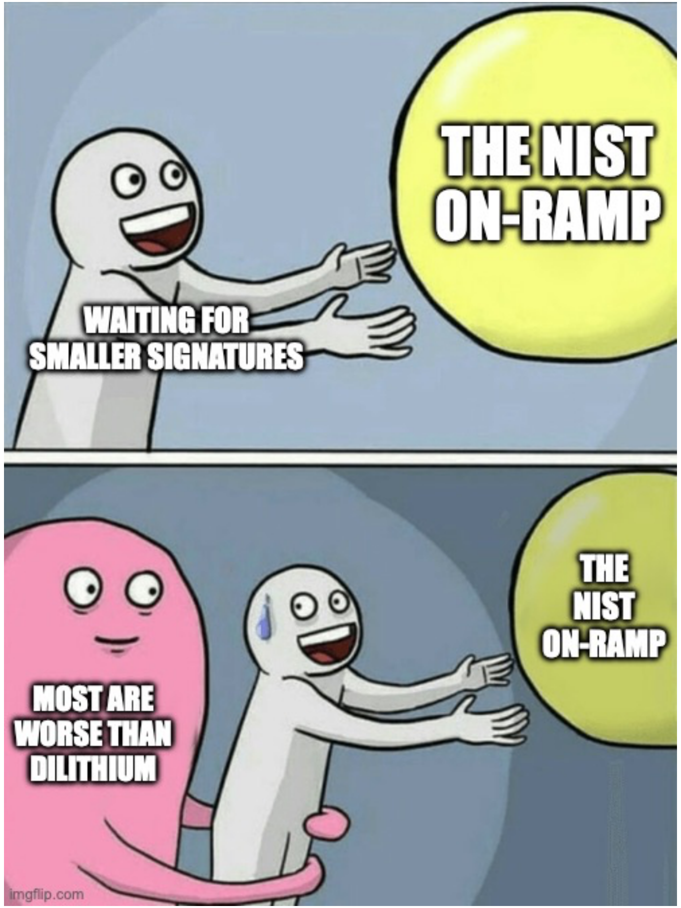
Request for Additional Digital Signature Schemes for the Post-Quantum Cryptography Standardization Process

September 06, 2022

2024-10-24 NIST round 2 selections

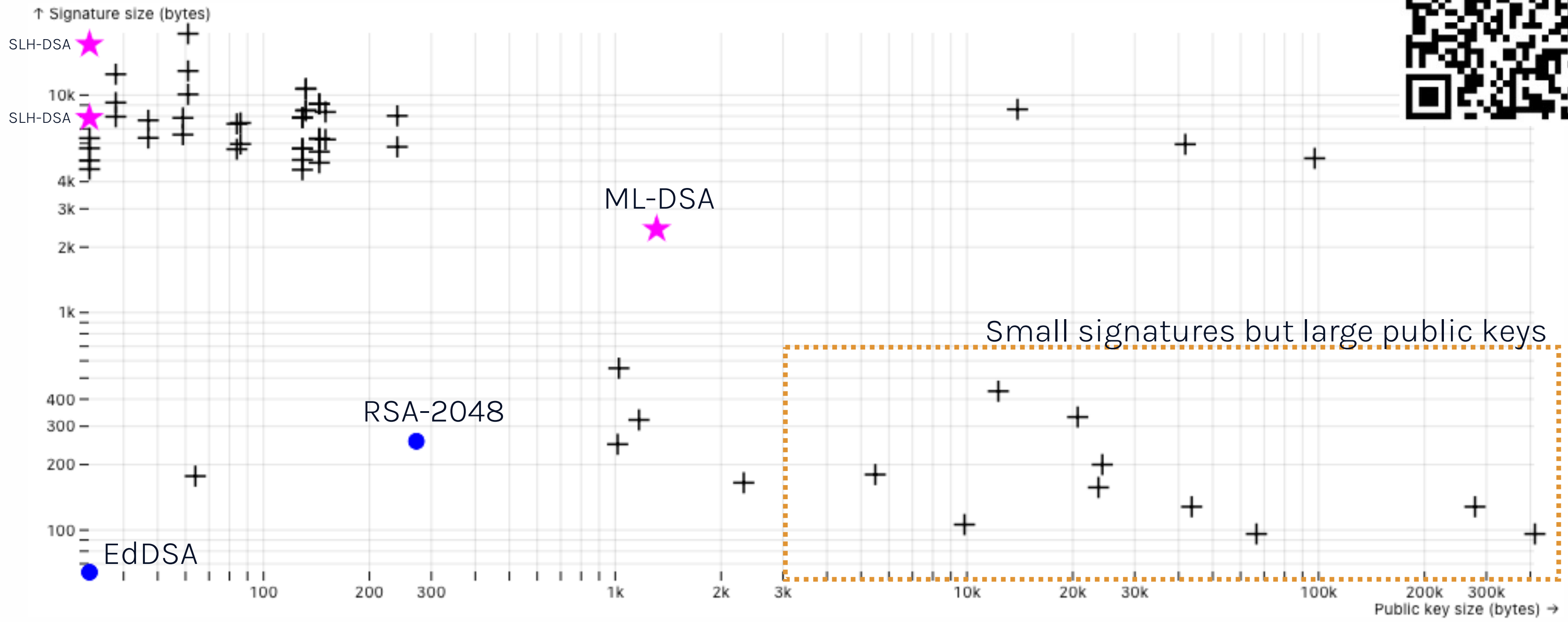
- Code-Based
  - LESS
  - CROSS
- Lattice-based
  - HAWK
- Symmetric-based
  - FAEST
- MPC-in-the-Head
  - Mirath
  - MQOM
  - PERK
  - RYDE
  - SDitH
- Isogeny-based
  - SQIsign
- Multivariate
  - UOV
  - MAYO
  - QR-UOV
  - SNOVA

Signatures will not get (much) better soon



Caveat: I'm ignoring different security assumptions and just focusing on practicalities

Key and signature sizes



NIST Level-I parametersets

https://pqshield.github.io/nist-sigs-zoo/

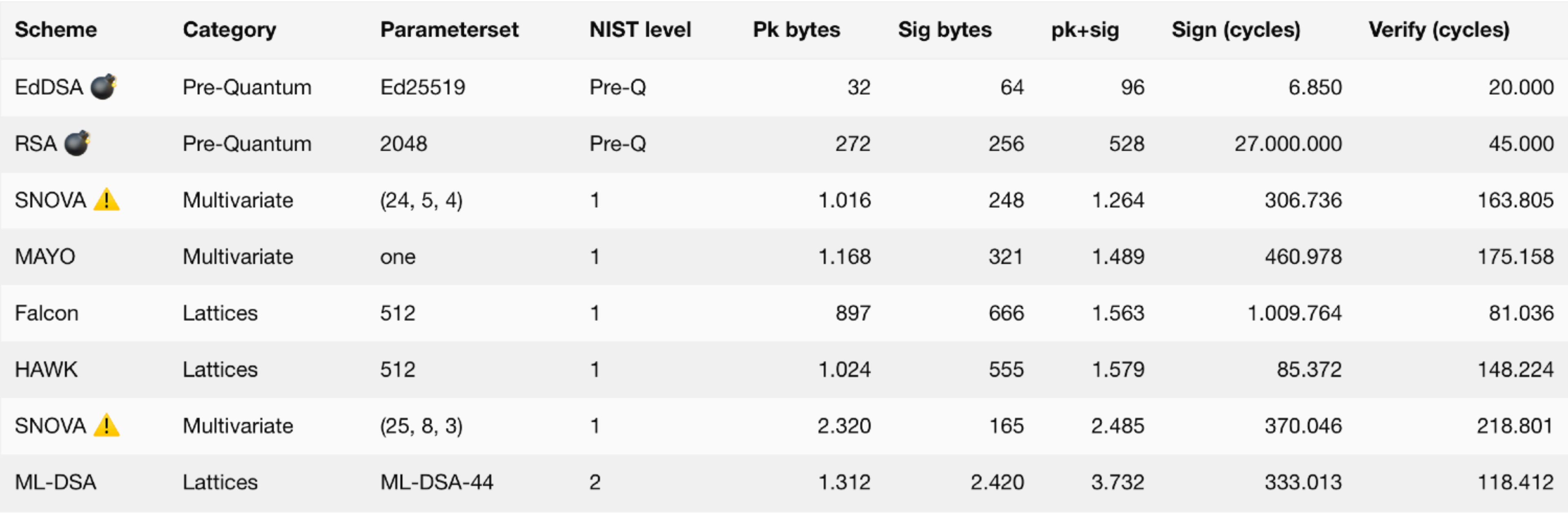
Too Big: pk+sig < 4000 bytes

- Code-Based
  - ~~LESS~~
  - ~~CROSS~~
- Lattice-based
  - **HAWK**
- Symmetric-based
  - ~~FAEST~~
- MPC-in-the-Head
  - ~~Mirath~~
  - ~~MQOM~~
  - ~~PERK~~
  - ~~RYDE~~
  - ~~SDitH~~
- Isogeny-based
  - **SQIsign**
- Multivariate
  - ~~UOV~~
  - **MAYO**
  - ~~QR-UOV~~
  - **SNOVA**

Too Slow: verification < 10ms

- Code-Based
  - ~~LESS~~
  - ~~CROSS~~
- Lattice-based
  - **HAWK**
- Symmetric-based
  - ~~FAEST~~
- MPC-in-the-Head
  - ~~Mirath~~
  - ~~MQOM~~
  - ~~PERK~~
  - ~~RYDE~~
  - ~~SDitH~~
- Isogeny-based
  - ~~**SQIsign**~~
- Multivariate
  - ~~UOV~~
  - **MAYO**
  - ~~QR-UOV~~
  - **SNOVA**

Shout-out: SNOVA got 50x faster since Round 1!



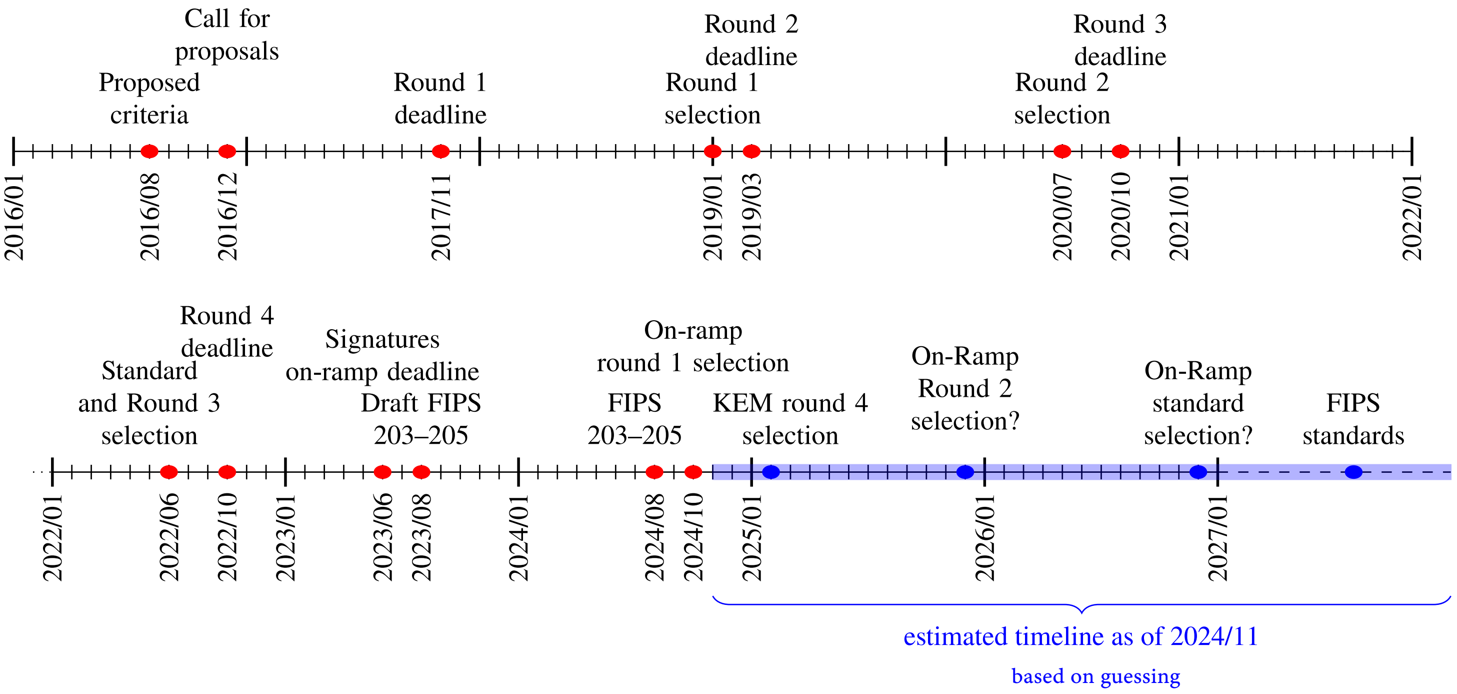
Scheme	Category	Parameterset	NIST level	Pk bytes	Sig bytes	pk+sig	Sign (cycles)	Verify (cycles)
EdDSA 💣	Pre-Quantum	Ed25519	Pre-Q	32	64	96	6.850	20.000
RSA 💣	Pre-Quantum	2048	Pre-Q	272	256	528	27.000.000	45.000
SNOVA ⚠️	Multivariate	(24, 5, 4)	1	1.016	248	1.264	306.736	163.805
MAYO	Multivariate	one	1	1.168	321	1.489	460.978	175.158
Falcon	Lattices	512	1	897	666	1.563	1.009.764	81.036
HAWK	Lattices	512	1	1.024	555	1.579	85.372	148.224
SNOVA ⚠️	Multivariate	(25, 8, 3)	1	2.320	165	2.485	370.046	218.801
ML-DSA	Lattices	ML-DSA-44	2	1.312	2.420	3.732	333.013	118.412

https://pqshield.github.io/nist-sigs-zoo/

Promising candidates

- MAYO:
  - Best name and logo
  - Very new assumptions
  - I hope it survives
- SNOVA:
  - Perf improvements make it now very attractive
  - Structured variant of UOV
  - Already getting attacked
- HAWK:
  - Evolution of Falcon
  - Less-studied security assumptions than Falcon
  - Easier to securely implement than Falcon
  - Will NIST keep an even more spicy modular-lattice based scheme?

When will NIST be done?



The On-Ramp for Signatures

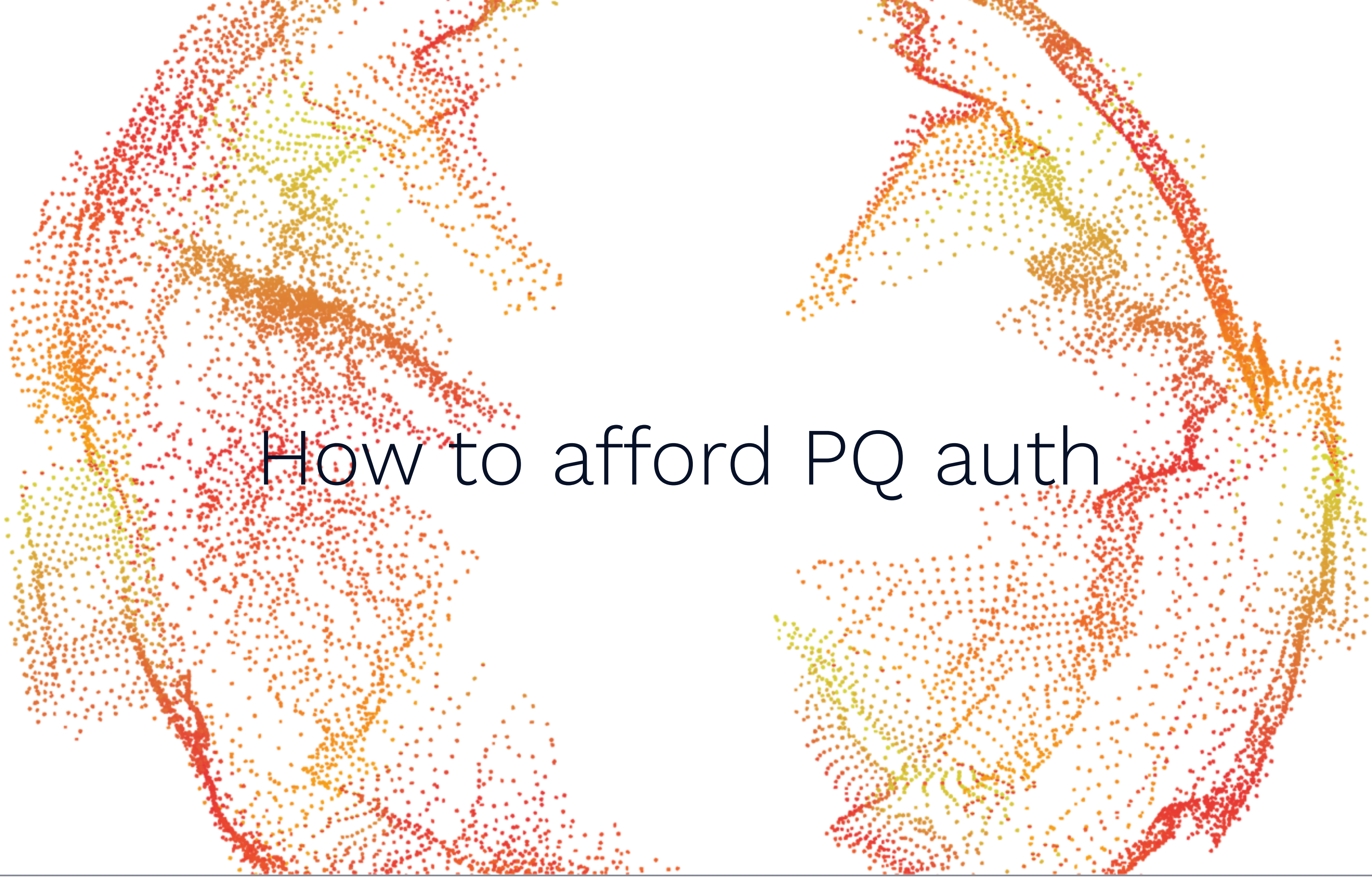
- Only a few “better” algorithms with potential (for general applicability)
- Academics are still working out their security
- In any case, NIST won’t likely be done soon

What about new KEMs?

- NIST still on Round 4 of KEM standardisation
  - ML-KEM (Kyber) got standardised, based on lattices
  - ML-KEM-512 pk: 800 bytes, ciphertext: 768 bytes
- BIKE:
  - Based on error-correcting codes
  - BIKE-1 pk: 12323 bytes, ct: 12579 bytes
- HQC:
  - Based on different error-correcting codes
  - HQC-1 pk: 2249 bytes, ct: 4497 bytes
- Classic McEliece
  - Based on McEliece (1978) (error-correcting codes)
  - McEliece-34864: pk 261120 bytes, ct: 96 bytes

Takeaway:

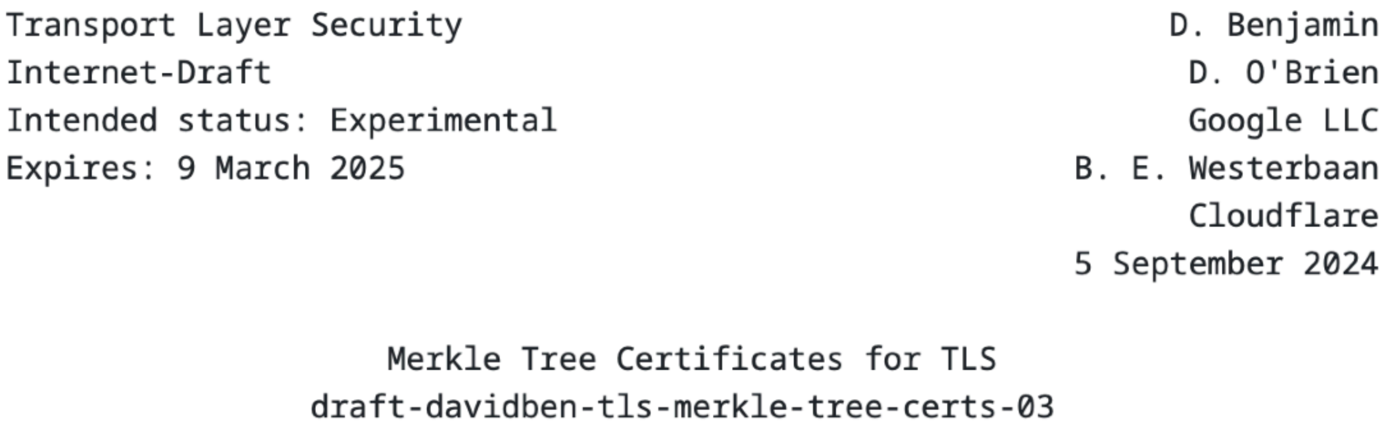
Useful for diversification,
Or if you can make use of
McEliece’s trade-off in sizes



How to afford PQ auth

Radical proposals: Merkle Tree Certificates

What if we just fully reconsider how authentication works in TLS?



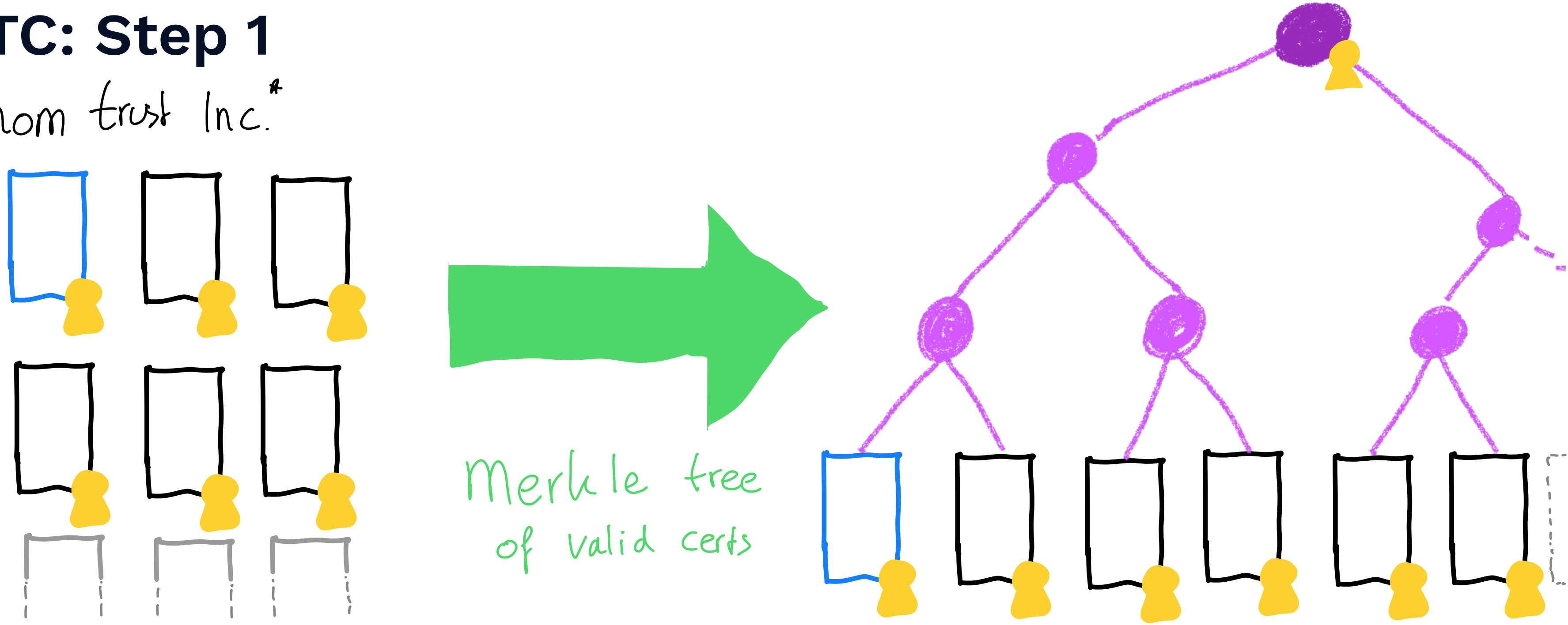
```
Transport Layer Security                                 D. Benjamin
Internet-Draft                                            D. O'Brien
Intended status: Experimental                             Google LLC
Expires: 9 March 2025                                B. E. Westerbaan
                                                          Cloudflare
                                                    5 September 2024


                  Merkle Tree Certificates for TLS
               draft-davidben-tls-merkle-tree-certs-03
```

https://datatracker.ietf.org/doc/draft-davidben-tls-merkle-tree-certs/

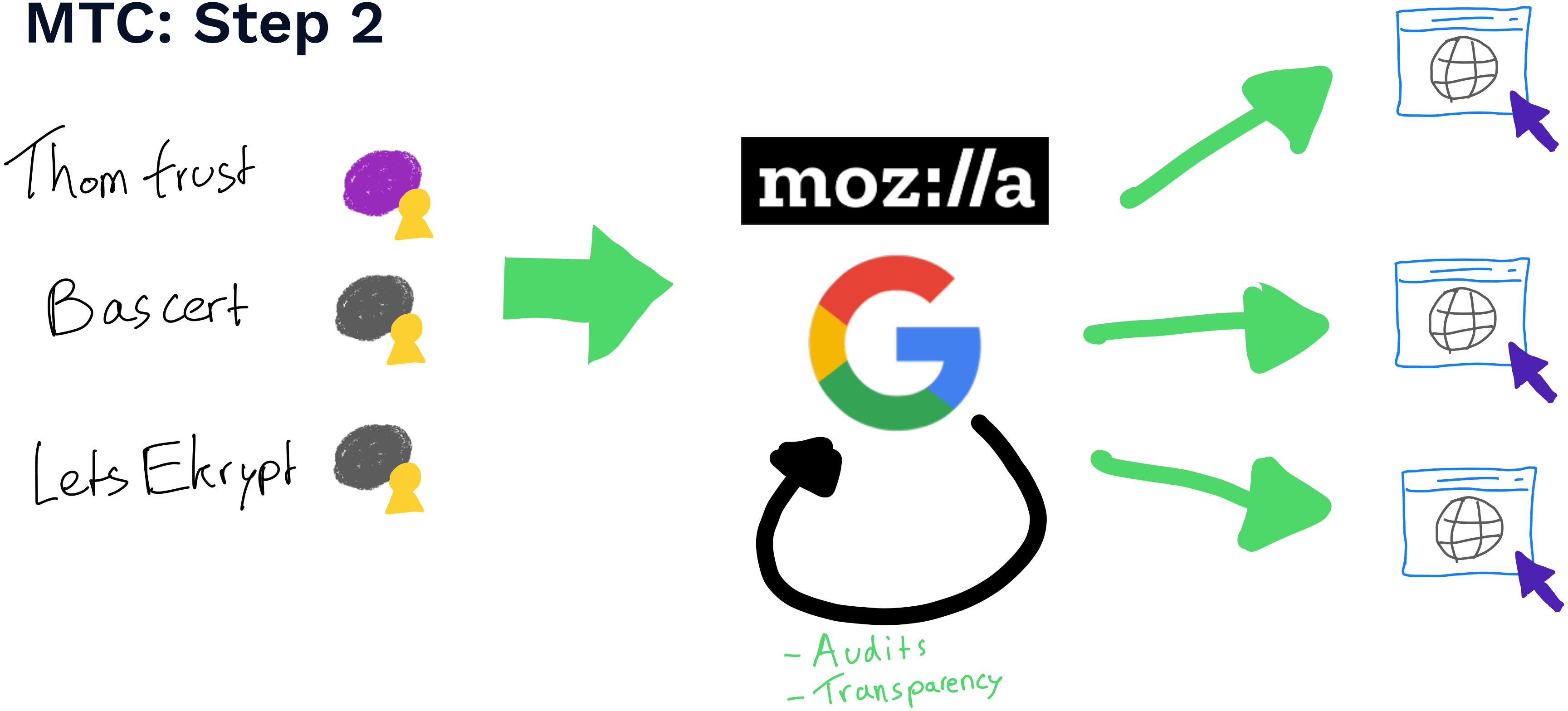
MTC: Step 1

Thom trust Inc.*

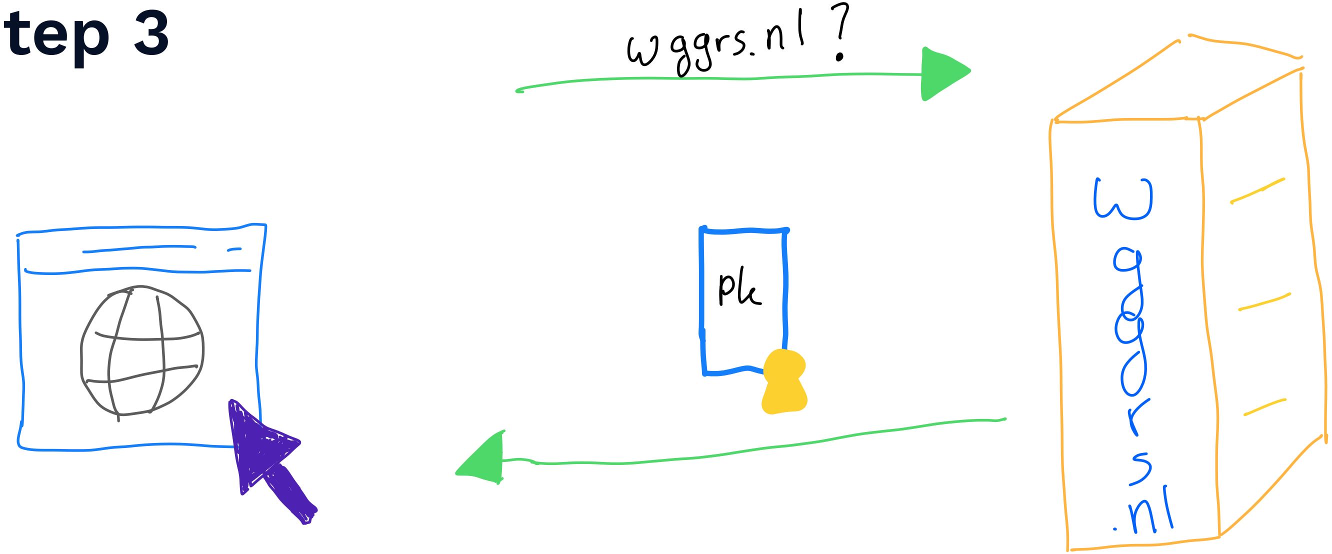


* Fund my Startup

MTC: Step 2

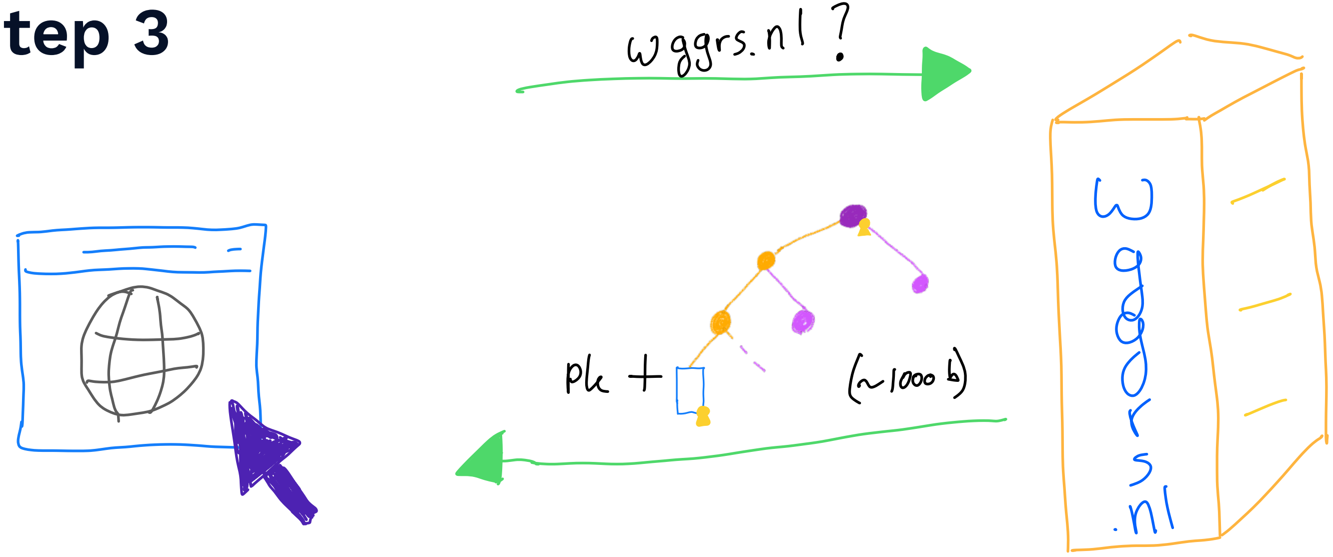


MTC: Step 3



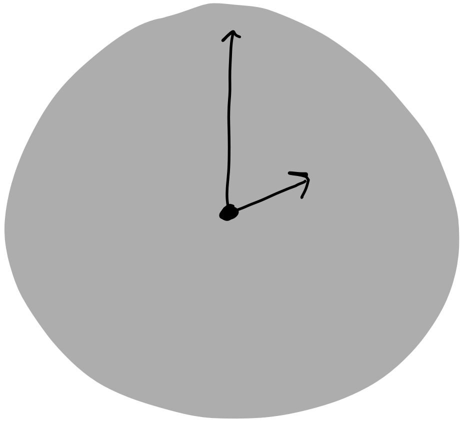
Without MTC

MTC: Step 3



With MTC

Merkle Tree Certificates



Repeat every hour

Merkle Tree Certificates

- Takeaway: Reconsideration of the status quo can result in significant savings
  - MTC still saves data for classical cryptography!

- But: Big changes necessary to every part of the TLS ecosystem
  - Short-lived certificates
  - Webserver must continuously fetch the latest authentication paths
  - Clients must keep downloading currently valid tree heads
  - Automated certificate provisioning such as ACME [RFC8555] should help with this
- New trust model makes security analysis more complicated

- MTC is designed for big deployments and publicly trusted CAs
  - What about IoT? What about a bank's internal stuff?

Finally: we're not done yet

- Boring cryptography: KEM and Signatures (and hashes, symmetric encryption, ...)
  - Solves obvious problems in obvious ways
- Fancy cryptography solves subtle privacy and security problems

Anonymous credentials and zero-knowledge proofs in Signal's private group system. Oblivious PAKEs in WhatsApp's encrypted backups, and regular ones in Magic Wormhole. Unlinkable tokens in Apple Private Relay (blind signatures), Privacy Pass (OPRF), and Dutch CoronaCheck app (Idemix). Attribute-Based Encryption in Cloudflare's GeoKDL. Private set intersection with blinding for password protection in Chrome.

We're working on a list: https://github.com/fancy-cryptography/fancy-cryptography

Thanks Bas Westerbaan for the examples in this slide

Fancy cryptography requires fancy research

- More research is needed to develop (practical, efficient) building blocks to migrate fancy cryptography to a post-quantum world
- Fancy cryptography problems often compete with not doing anything
- If we don’t solve these problems, we could seriously regress on privacy

Upside: you like know it if you are using fancy cryptography.

We need to think about authentication today

- Where does post-quantum authentication hurt?
- How do we make PQ authentication attractive enough to get people to adopt?
- Can we change protocols to solve our authentication needs with fewer (big, PQ) signatures?
  - Maybe we can use KEMs to do authentication [SS**W**20]
  - Work that you put in today, will still pay off if NIST standardises a smaller scheme
- Ask your protocol designers and developers what happens when you switch to ML-DSA
- Even though things might be fine in theory, practice might require big investments
- While solving Key Exchange first, don't forget to consider authentication

Thanks for your attention

[SSW20] Peter Schwabe, Douglas Stebila, Thom Wiggers (2020). Post-Quantum TLS without handshake signatures. ACM CCS 2020.