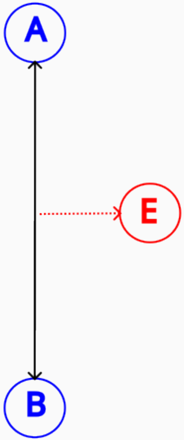
CACHAÇA
Compact Asymmetric Crypto with High Assurance for Constrained Applications

Benjamin **Smith**

Équipe-Projet **GRACE** // **Inria SACLAY**

Inria-ECDF partnership kickoff // 07/06/2024

Cryptography: the science of secrecy and authenticity



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In 2024: strong cryptography is **ubiquitous**.

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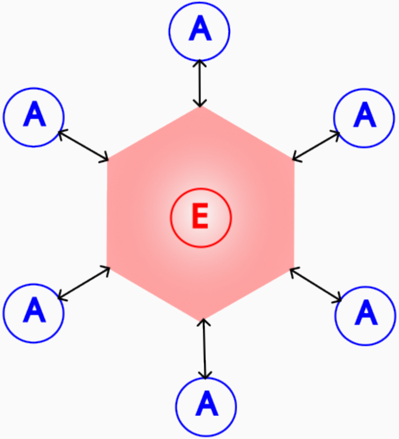

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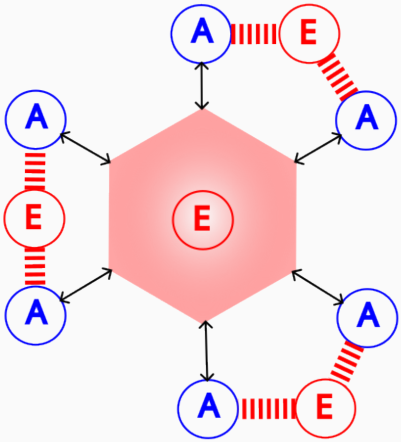

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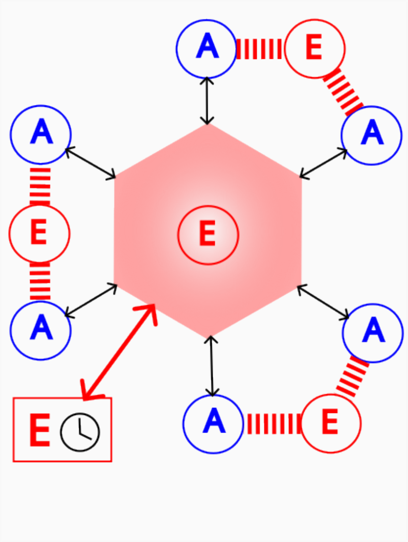

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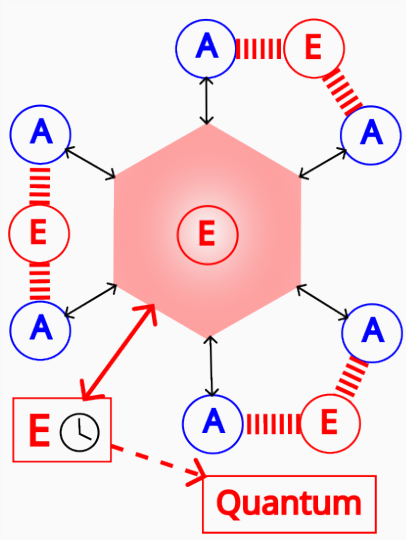

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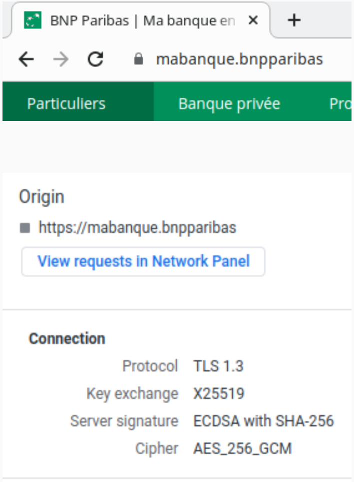
+ *Future quantum adversaries*

Breaking protocols down into primitives



Protocol: **Transport Layer Security** (TLS) v**1.3**

Primitives: asymmetric (public-key) & symmetric

- X25519: **elliptic-curve key exchange**
- ECDSA: elliptic-curve **digital signature**
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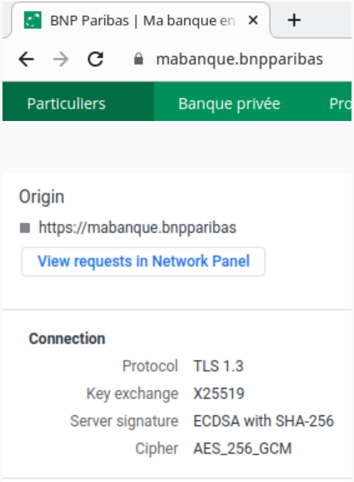

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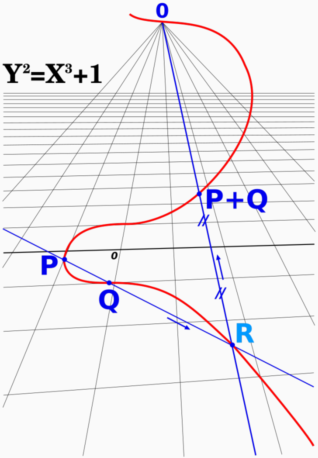

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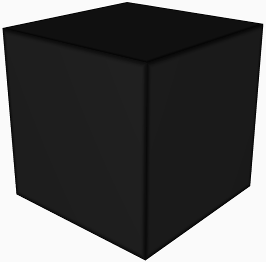
Challenge: translating the mathematics into
high-security, high-performance implementations

Post-quantum cryptography

Quantum Threat

Shor's algorithm (1994): polynomial-time integer factorization and discrete logs.

Breaks RSA and **Elliptic Curve** Crypto (ECC) *i.e., all deployed public-key crypto*



We need quantum-safe crypto ***now****:*

- Adversaries **store now, decrypt later**
- **Infrastructure**:
  - root certificates have 10-year lifetimes
  - smart meters have 20-year lifetimes
  - ...
- **Government** policy requirements

Post-quantum cryptosystems: run on classical machines, resist quantum attacks.

Post-quantum for the real world

Everyone needs post-quantum security, now.

The transition will take at least a decade.

The first wave of standards is here, but cannot meet all our needs.

Action Exploratoire **CACHACA** at Campus Cyber: developing

1. **new** post-quantum cryptosystems
2. with high-assurance **implementations**
3. with better **performance**
4. for **real-world applications**, especially in **constrained environments**.

Action Exploratoire CACHAÇA

→ Senior researchers: B. Smith (Inria) and G. Renault (ANSSI)

→ Postdoc:

- B. Sterner **isogeny-based crypto**
- *Looking for more!*

→ PhD students

- A. Le Dévéhat (PEPR): **compact PQ signatures** & **isogeny cryptanalysis**
- A. Ras (CEA LETI): **agile post-quantum coprocessor hardware**
- A. Moran (CEA LETI): **post-quantum side-channel** attacks
- O. Belbahi (with PROSECCO): **formally verified** implementation of **Falcon**

→ **Microcontroller implementations** with G. Banegas (Qualcomm)

→ Continuing work with the **RIOT** project

→ France2030 industrial consortium **HYPERFORM**

Case study:
Post-quantum software updates for low-end IoT devices

Post-quantum software updates for IoT

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Problem: updating **low-end IoT devices** (low power, low memory, low price) running **RIOT** (a free, community-driven open-source OS).

RIOT supports **SUIT** (RFC 9019): **S**ecure **U**pdates for the **I**nternet of **T**hings.
Critical cryptographic component: ***elliptic-curve digital signatures***.

Question: what is the real cost of adding post-quantum security to SUIT?

Post-quantum software updates for IoT

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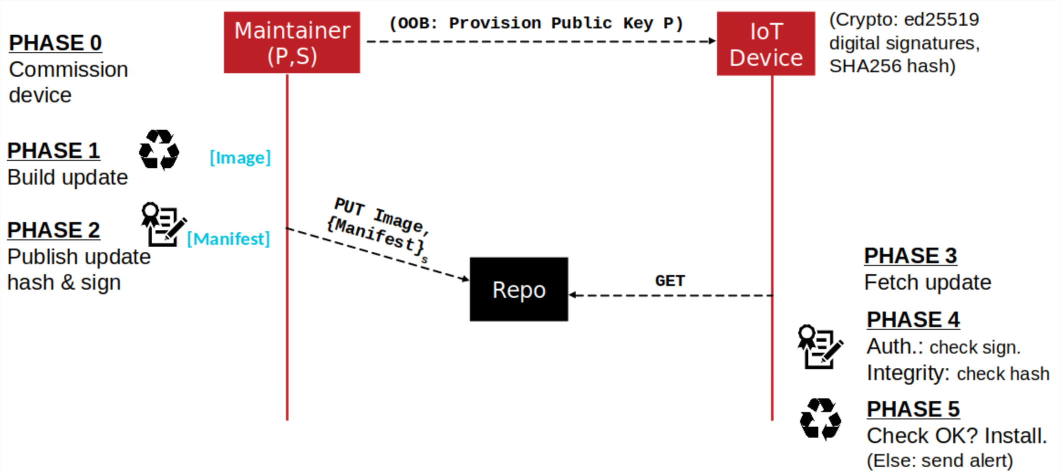
Banegas–Herrmann–Zandberg–Baccelli–**S.** (ACNS + RWC 2022): transverse study

- → **Dilithium** vs **Falcon** vs **LMS** vs Elliptic Curves
- → **ARM Cortex-M4** vs **ESP** vs **RISC-V**
- → Small firmware updates vs full software packages

SUIT: Software Updates for the Internet of Things



What we measured: pre- and post-quantum signature schemes

Pre-quantum baseline (SUIT standard) and **Post-quantum alternatives**

	Private key		Public key		Signature		SUIT Manifest	
Algorithm	Bytes	*Ratio*	Bytes	*Ratio*	Bytes	*Ratio*	Bytes	*Ratio*
Ed25519 *or* **ECDSA**	32	*1*×	32	*1*×	64	*1*×	483	*1*×
Dynamic[1] **Dilithium**	2528	*79*×	1312	*41*×	2420	*37.8*×	2839	*5.88*×
Static[2] **Dilithium**	18912	*591*×	17696	*553*×				
Falcon	1281	*40*×	897	*28*×	666	*10.4*×	1085	*2.24*×
LMS[3] (RFC8554)	64	*2*×	60	*0.94*×	4756	*74.3*×	5175	*10.7*×

[1] *Dynamic Dilithium* = "standard".
[2] *Static Dilithium* = matrices expanded from seed and stored.
[3] LMS = Leighton–Micali, stateful hash-based signatures. State is not a problem for this application.

Three boards representing the 32-bit microcontroller landscape

RIOT supports ≥ 240 platforms: we have to emphasize **portability**.

- No assembly, no platform-specific tricks.
- Open implementations (notably `PQClean`)
- Minimal modifications for RIOT compatibility: removing `malloc`, etc.

We took **three** representative 32-bit boards:

Architecture	Board	Speed	RAM (kB)	Flash (kB)
ARM Cortex-M4	Nordic nRF52480	64MHz	256	1024
Espressif ESP32	WROOM-32	80MHz	520	448
RISC V	Sipeed Longan Nano	72MHz	32	128

Signature benchmarks: Verification on ARM Cortex-M4

Algorithm	Base library	Flash (B)	Stack (B)	Time (ms)
Ed25519	C25519	5106	1300	1953
Ed25519	Monocypher	13852	1936	40
ECDSA	Tinycrypt	6498	1024	313
Dynamic **Dilithium**	PQClean	11664	**36058**	53
Static **Dilithium**	PQClean	**26672**	**19504**	23
Falcon	PQClean	**57613**	4744	15
LMS (RFC8554)	Cisco	12864	1580	**123**

- Similar figures for ESP32 and RISC-V
- Dynamic Dilithium cannot run on the Sipeed Nano (RISC-V): only 32kB RAM

Impact on data transfer

Example: suppose we want to update RIOT firmware for the `nRF52480` board. The firmware itself is a $\approx$ 46kB binary, and the (pre-quantum) crypto is $\approx$ 6kB.

How much data do we need to transmit?

SUIT				Data Transfer	
Signature	Hash	Flash	Stack	**no crypto**	**crypto incl.**
Ed25519	SHA256	52.4kB	16.3kB	47kB	53kB
Dilithium	SHA3-256	+30%	+210%	+4.3%	+34%
Falcon	SHA3-256	+120%	+18%	+1.1%	+120%
LMS	SHA3-256	+34%	+1.2%	+9%	+43%

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3. **Small firmware update** $\approx$ 50kB *plus* crypto libs $\implies$ prefer **LMS**
   Larger crypto lib transfer $\implies$ *higher energy cost on low-power networks.*
   It takes 30-60s to transfer 50kB on a low-power IEEE802.15.4 radio link,
   but signature verification only varies by 2s between all candidates...
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4. **Large firmware update** $\approx$ 250kB $\implies$ **no preference**
   Network transfer costs overwhelm other factors, reducing relative advantages

Conclusions

Post-quantum IoT software updates with SUIT are **feasible now**.

- **Falcon** is best for smaller module and firmware updates;
- **LMS** is better when the crypto lib is transferred;
- but there is no clear winner for much larger updates.

Consider using RIOT for easy, portable, open IoT crypto development.

`https://riot-os.org/`
`https://ia.cr/2021/781`