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Quantum-resistant digital signatures schemes for low-power IoT

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Seminar Internet of Things, 2021

Outline

Motivation

- Quantum Computing
- Internet of Things

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Quantum Resistant Signature Schemes

- Performance Metrics
- different types
  - HBS
  - LBS

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Comparison
- FALCON
- Dilithium

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Quantum Computing breaks ordinary Cryptography

- sufficiently sized Quantum Computers (explained later) on the horizon
- They can break most of the cryptography in current use
  - RSA
  - ECDSA / ECDH
  - $\rightarrow$ Signal, WhatsApp, PGP, SSH, TLS/HTTPS, ...
- not everything equally effected
  - schemes in standardization to replace current cryptography
  - some are rather computationally intense
  - that is why i have a deeper look on which are feasable for IoT

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Conclusion

Ressources

Shors algorithm poses threat against asymmetric cryptography

- Quantum Computers operate on Qubits instead of normal Bits

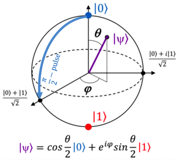

Figure: Model of a qubit [3]

- Algorithms can leverage those mechanics
  - up to exponential speed up in some cases
  - Shors algorithm completely breaks common asymmetric cryptography
    - can derive private key from public key
    - for everything based on Number-Theory (like RSA, ECDSA, ..)
  - Grovers algorithm poses threat against symmetric crypto and hash-functions
    - only quadratic speed-up
    - doubling length restores security (e.g. AES128 $\mapsto$ AES256)

Shors and Grovers algorithms

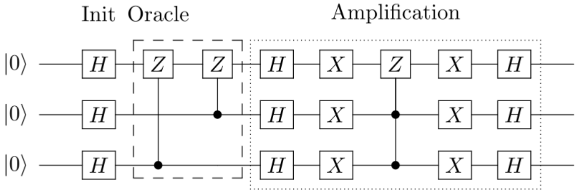

Figure: Grovers Algorithm [4]

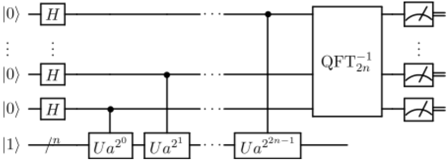

Figure: Shors Algorithm[5]

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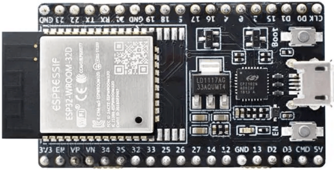
Many ressource constrained devices

- Internet of Things
- Smart-devices that are actually pretty dumb
  - little memory (kilobytes to megabytes)
  - low computing power (slow clock, small cache, etc.)
  - limited energy ressources (battery or solar operated)
- NIST classified into 3 classes:

Table: IETF IoT Classes

Class	RAM	Flash
C0	<< 10 KiB	<< 100 KiB
C1	10 KiB	100 KiB
C2	50 KiB	250 KiB



Outline

What makes a signature scheme better than any other?

- length of:
  - signature
  - public key
  - private key
- time and space needed to:
  - generate keys (GEN)
  - sign a message (SIGN)
  - verify a message (VER)
- security against quantum computers and traditional attackers

Table: QR Security classes and their traditional counterparts as classified by the NIST

Class	security comparable to
1	AES-128
2	SHA256
3	AES-192
4	SHA384
5	AES-256

Outline

Multiple types of underlying mathematica problems

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- Super-singular isogeny based
  - SIKE
  - not well studied
- Multivariate polynomial based
  - Rainbow
  - not well studied
  - involves guessing work $\rightarrow$ not suited for low power devices
- Code based
  - McEliece
  - no finalist
- Hash based
  - SPHINCS+
  - big signatures (see next slide)
  - very well studied
- Lattice based
  - FALCON, Dilithium
  - most promising
  - most NIST finalists
  - most efficient
  - not as proofed as HBS

Hash Based Signatures

- Bases security upon Pre-Image resistance (of hash-functions) $\rightarrow$Well-Studied
- most simple form Lamport OTS:
  - private key: $2n$ random strings (two for each bit in digest)
  - public key: hash of these strings
  - sign by publishing one string for every bit in digest (either first or second)
- only useable one-time $\rightarrow$ publish x keys for x private keys
  - greatly improved by use of Merkle tree (no need for x keys, only one public)
  - but increases signature size by $\log(x)$

Lattice Based Signatures

- Bases security upon hardness ov CVP
  - find closest vector in a (High-d) Lattice
  - private key: short basis (red)
  - public key: long basis (black)
  - sign by providing a lattice vector close to a point on which the message would be mapped
  - hard with long basis but easy to verify
- keys are giant since high d requires $\mathcal{O}(d^2)$ scalars.
- reduce by introducing symmetries (NTRU[1])
- every signature leaks information about private key
  - don't give closest vector, but a close enough one
  - best to use gauss-sampling, but cryptographically hard

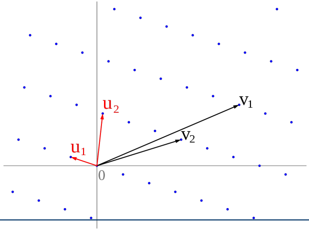

Table: Stack usage

Implementation name	GEN (bytes)	SIGN (bytes)	VER (bytes)
Dilithium-3 [21]	50k	86k	54k
2021 Dilithium(dyn)[10]	-	52k	36k
2021 Dilithium(sta)[10]	/ [2]	35k	19k
qTESLA-1 [21]	22k	29k	23k
qTESLA-3 [21]	43k	28k	45k
Falcon-5 [21]	120k	120k	120k
2021 FALCON [10]	-	42k	4.7k

Table: clock cycles

Implementation name	GEN	SIGN	VER
Dilithium-3 [21]	2.3	8.3	2.3
Dilithium-3 [23]	2.1	7.2	2.1
2021 Dilithium(dyn)[10]	-	29	3.4
2021 Dilithium(sta)[10]	-	8	1.5
qTESLA-3 [21]	30	11	2.2
Falcon-5 [21]	365	165	1
2021 Falcon [10]	-	75	1 [3]

Table: Flash sizes)

Scheme	Size
FALCON	57KB
2021 Dilithium (Dyn)	11KB
2021 Dilithium (Sta)	26KB

Table: key and signature sizes

Scheme	public key	signature
SPHINCS	1KB	43KB
Dilithium-3	1.4KB	2.7KB
FALCON-1	900B	690B
FALCON-5	1.7KB	1.3KB
ECDSA	64B	64B

[2] precomputed key and directly stored in flash
[3] after optimizations these could be improved by further 43% [24]

Outline

FALCON is the fastest verifier

- most efficient by far for verification
  - smallest public key
  - smallest signature
  - fastest to verify
- great for verification only actors
- signing takes very long (1s)
  - since gauss sampling is used
  - also vulnerable to timing / side channel attacks (shown effective)

Outline

Dilithium is the best allrounder

- also great verification efficiency
- ditched gauss sampling
  - no FFT or FPA
  - everything in constant time $\rightarrow$ no timing attacks

QR IoT is possible

- two viable contenders for QR signatures in IOT:
  - Dilithium
  - FALCON
- already implemented with some kind of optimization
- still probably a little way up to key-length of ECDSA
- but already feasable for C2 devices and FALCON VER on C1

Ressources I

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