Bringing Ethereum to Post Quantum Era

Implementation results and foresight

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ZKNOX

Advancing Hardware security and Cryptography

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Summary

1. Introduction
   - ZKNOX
   - Quantum Apocalypse
   - Solutions
2. Verifiers implementation
3. Signers implementation 

4. The ZK endgame 

5. Conclusion

Casting

Nicolas Bacca
20+ years experience (10y+ web3)
Security and hardware specialist
Prev. Ledger cofounder/CTO

Renaud Dubois
20+ years experience (3+ web3)
Cryptographer
Prev. Ledger, Thales (Defense Industry)

Simon Masson
8+ years experience (4y+ web3)
Cryptographer
Prev. Heliax, Thales

Missions

Bring deep expertise and innovation to every challenge on the whole security chain

- user end (be it secure enclaves, hardware wallets)
- back end (TEE, HSMs)
- on-chain (smart contracts)
- academic research

Blog

Github

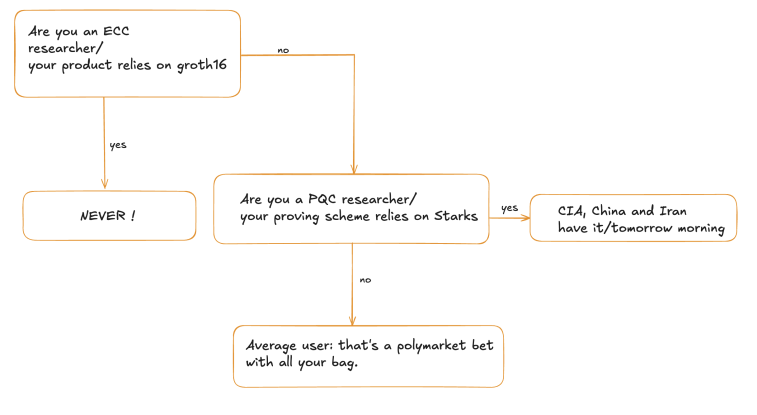
What is Quantum Apocalypse ?

Shor algorithm solves factorization and discrete logarithm problems.

What is Quantum Apocalypse ?

WHEN ?

What is Quantum Apocalypse ?



What is Quantum Apocalypse ?

Remarks:

- Authentication must be solved later, (but we shall on the shelf solution).
- Confidentiality shall be solved **NOW**.

Ethereum components at risk:

- EoA private keys (notably using ECDSA)
- Private Payments (Private Pool, RAILGUN)
- BLS signatures in consensus
- Data Availability Sampling (leveraging KZG commitments)

ZKNOX current roadmap is to solve all but last point. (Design and integrate signature schemes, not proving scheme).

Candidates

IACR has our back.

Complexity Metric	Falcon-512	Dilithium2	SPHINCS+	GeMSS
Public Key Size (Bytes)	897	1312	32	33
Private Key Size (Bytes)	7553	2528	32	64
Signature Size (Bytes)	666	2420	17088	21952

Table: **NIST Level 1 Complexities of Selected PQ Signature Candidates**

FALCON appears as the more suited for onchain complexities but is known for its signer integration to be a challenge.

Pleasant feature: FALCON has an recover version, which is similar to ecrecover functionning (recover public key from signature)

Progressive Roadmap

Verifier (On chain side)

- Step1: use Account Abstraction (EIP-7702+7579/4337) with full solidity to experiment ✓
- Step2: integrate RIP into nodes
- Step3: accept as EIP
- Final: remove eoA (EIP-7701/EIP-7560)

At first, solidity enables experiments on cheap L2s.

Signer (User side)

- Step1: Hot wallet
- Step2: Hardware wallet

Verifier: Implementation Results

Function	Description	Gas Cost
`TETRATION_ethfalcon.verify`	EVM Friendly*	24M
`ZKNOX_falcon.verify`	NIST	7M
`ZKNOX_ethfalcon.verify`	EVM Friendly	1.8M
`ZKNOX_epervier.verify`	Recover EVM friendly	1.9M

Table: Gas cost of ZKNOX FALCON verification functions

- In order to reduce gas cost, ETHFALCON and EPERVIER use Keccak instead of SHAKE, without compromising security.
- EPERVIER is a recover version which reduces complexity by tweaking public key representation, avoiding NTT inversion.
- Optimal NTT, fully Yuled

Verifier: Implementation Results

Function	Description	Gas Cost
TETRATION_ethdilithium.verify	EVM Friendly	40M
ZKNOX_dilithium.verify	NIST	13.5M
ZKNOX_ethdilithium.verify	EVM Friendly	6.6M

Table: Gas cost of ZKNOX DILITHIUM verification functions

Verifier: Conclusions

- FALCON x4 cheaper than DILITHIUM
- Straightforward to implement in Node, just follow NIST recommendations (see our Geth Fork)
- EVM friendly versions are preferable for step1
- NTT could be standardized rather than one or the other for more flexibility: EIP-7885
- Vectorization is very efficient to speed up NTT (EVMMAX experimentations), expected 80% gain.
- EVMMAX $\geq$ NTT, but harder to implement in Core.

Signers: constraints

Scheme	Operation	RAM Consumption (KiB)	Code Size (KiB)
Falcon	Key Generation	40-64	30-50
	Signing	40-64	30-50
Dilithium	Key Generation	≥ 7	15-25
	Signing	≥ 7	15-25

- Hot Wallet constraints are trivial.
- Hardware wallets limitations makes FALCON non trivial to integrate
- Vendors should make their homework, onchain constraints are prioritary

How to solve RAM limitation ?

Signers: limitless HW using Oblivious RAM

- Oblivious RAM extends device RAM by using host memory as an extension
- Requires confidentiality and integrity cipher of host memory
- While a long knowm mechanism, no Hardware Wallet implements it
- Should be in the firmware

Alternative is using an EVM wrapping syscalls, easier DX but slower.

Signers: Conclusions

- On chain constraints are prioritary. Ethereum shall lead the decision, not HW limitations.
- Oblivious RAM, plus other tricks can reduce dramatically implementation constraints
- Stay Tuned for more results

Proving FALCON/DILITHIUM

Need

- Allow FALCON/DILITHIUM integration into ZKEVM
- Allow PQ-Private Payments (PQ-Railgun)
- Solution for BLS replacement is Batching with snarks/starks.

Second one could use a dedicated scheme (LABRADOR).

Constraints

- FALCON and DILITHIUM operates on non native fields (Babybear, STwo)
- Non Native Fields require x30 more constraints (source: Bandersnatch vs P256 in Gnark, incoming paper)

ZKNOX aim: minimal tweak to obtain ZK friendly version

ZK friendly FALCON/DILITHIUM

Obvious tweaks

- Replace Hash function by a ZK friendly one
- Provide hints (see epervier definition) for easy batch inversion
- Accumulate several NTT steps, reduce once

Harder tweaks

- Starks fields are going shorter (no accumulation trick)
- Replacing fields is less trivial than for ECC (pick prime order curve and twist)
- FALCON is prone to overstretch attacks for ZK fields
- Estimator for S2/Babybear on dilithium provides 20% slowdown factor (WIP)

ZK Conclusion

- DILITHIUM is more ZK-friendly (and MPC too)
- Incoming zkDilithium vs zkFALCON paper
- Still experimental phase

Private Payments

- Three weaknesses: ECDSA in zkUTXOs, ECDH for ciphering of notes, proof Settlement
- PQ will break authenticity and settlement, not confidentiality
- Progressive Roadmap: modify cipher (easy), implement zkDilithium, use Stark (STwo/CairoM ?)

Conclusion

- Easy solutions for EOA migration
- EIP-7885 (NTT) to reduce gas costs, also reduce STARK proof cplx.
- Some efforts for HW signers, vendors will lobby for DILITHIUM
- Shall we tweak the proving scheme (LABRADOR) or the signature algorithm ?
- Privacy and Batching still very experimental, require STARKS with private input (proof size)

ZKNOX would gladly help Wallets/Dapps to integrate its framework.

Questions ?

Blog

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