ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

Quantum-Safe Blockchain

Evaluating the Feasibility of Introducing Quantum-Safe Digital Signatures For Blockchain Using the Example of a Minimal Python-based Blockchain

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“It’s time to prepare for quantum threats.”

- Dr. Lily Chen (mathematician and NIST fellow)

https://www.theverge.com/22523067/nist-challenge-quantum-safe-cryptography-computer-lattice

How feasible is the integration of quantum-safe signature algorithms into blockchains?

Select quantum-safe algorithms to evaluate

Implement Python blockchain (classic and quantum-safe)

Conduct comparison by measuring perf. / attributes

Hash-based Cryptography
rely on secure cryptographic hash functions, which exhibit properties like being difficult to reverse, resistant to finding original inputs,
and robust against collision attacks

Lattice-based Cryptography
sets of points arranged periodically in multi-dimensional spaces. Lattice-based systems are founded on the shortest vector problem (finding the smallest non-zero point within a lattice), which is NP-hard

Multivariante Cryptography
rely on the complexity of multivariate system of equations, which have been demonstrated to be NP-complete or NP-hard

First group of winners from NIST's six-year competition

CYSTALS-Dilithium, FALCON, SPHINCS+

https://www.nist.gov/news-events/news/2022/07/nist-announces-first-four-quantum-resistant-cryptographic-algorithms

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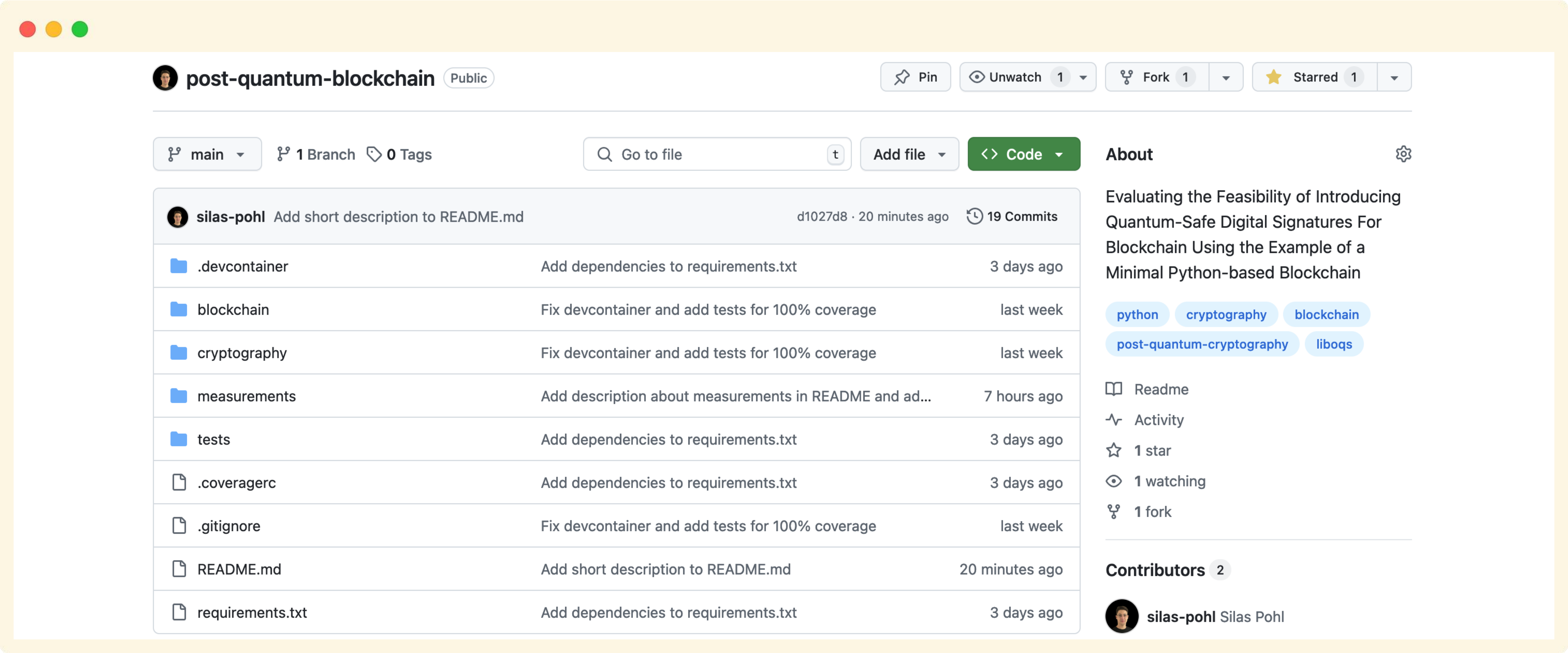


https://github.com/silas-pohl/post-quantum-blockchain

Select quantum-safe algorithms to evaluate

Implement Python blockchain (classic and quantum-safe)

Conduct comparison by measuring performance

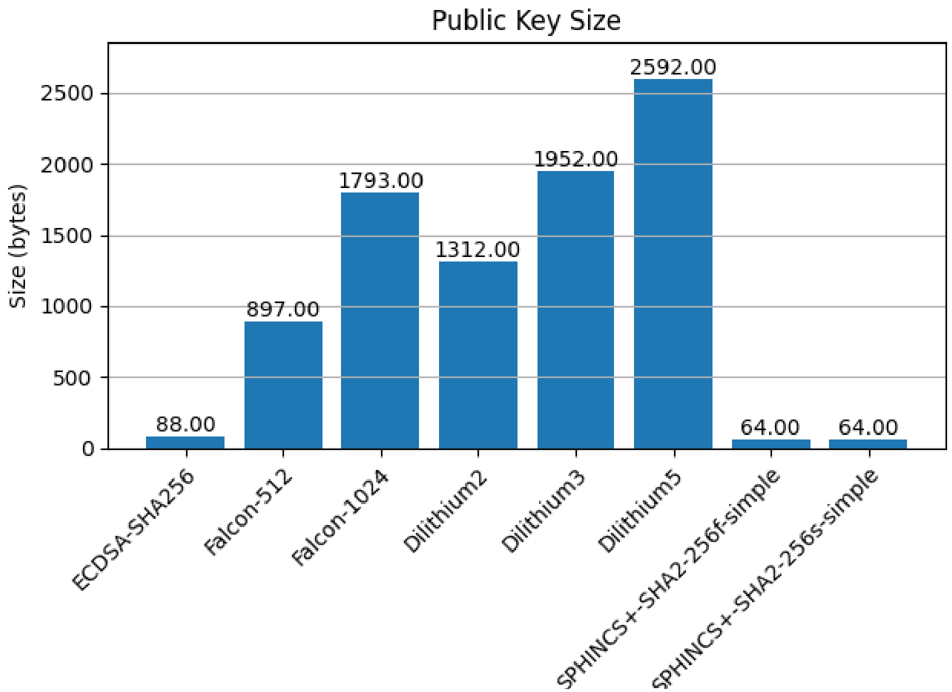
Public & Secret Key Sizes	**Signature Size**	**Blockchain Storage**
Transaction Time	**Verification Time**	**Mining Time**

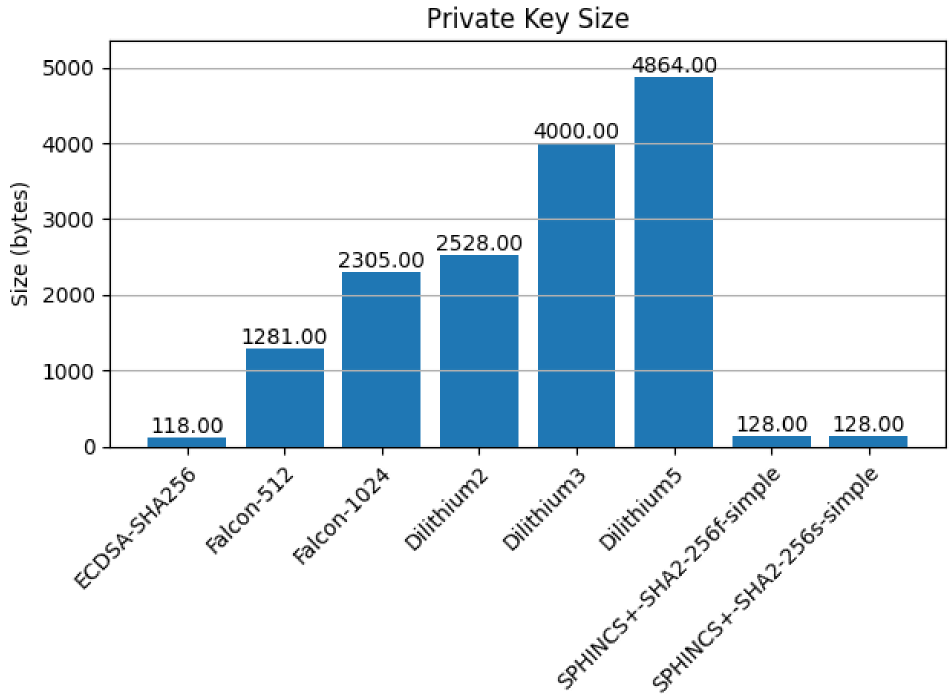
SHOWCASE

RESULTS

Public & Private Key Size

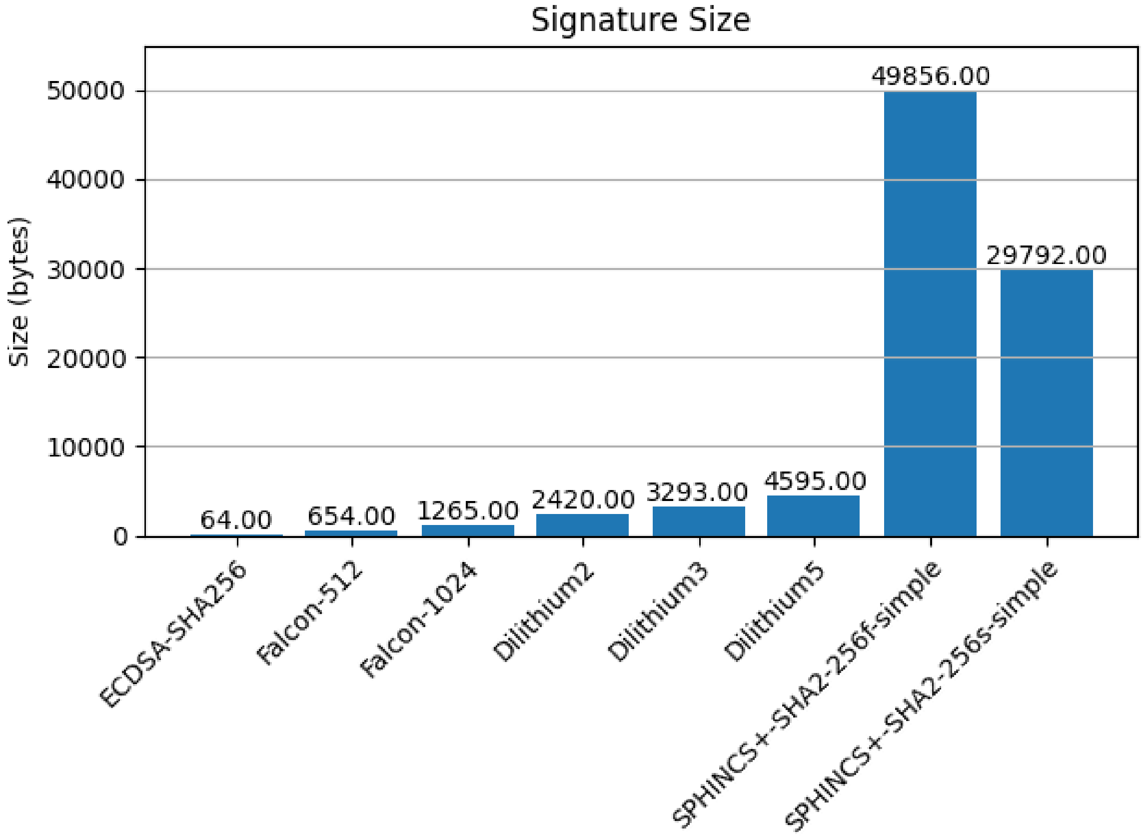
- Larger key sizes are designed to resist attacks, but result in larger transaction data size
- Smaller key sizes help improve performance in high-throughput environments





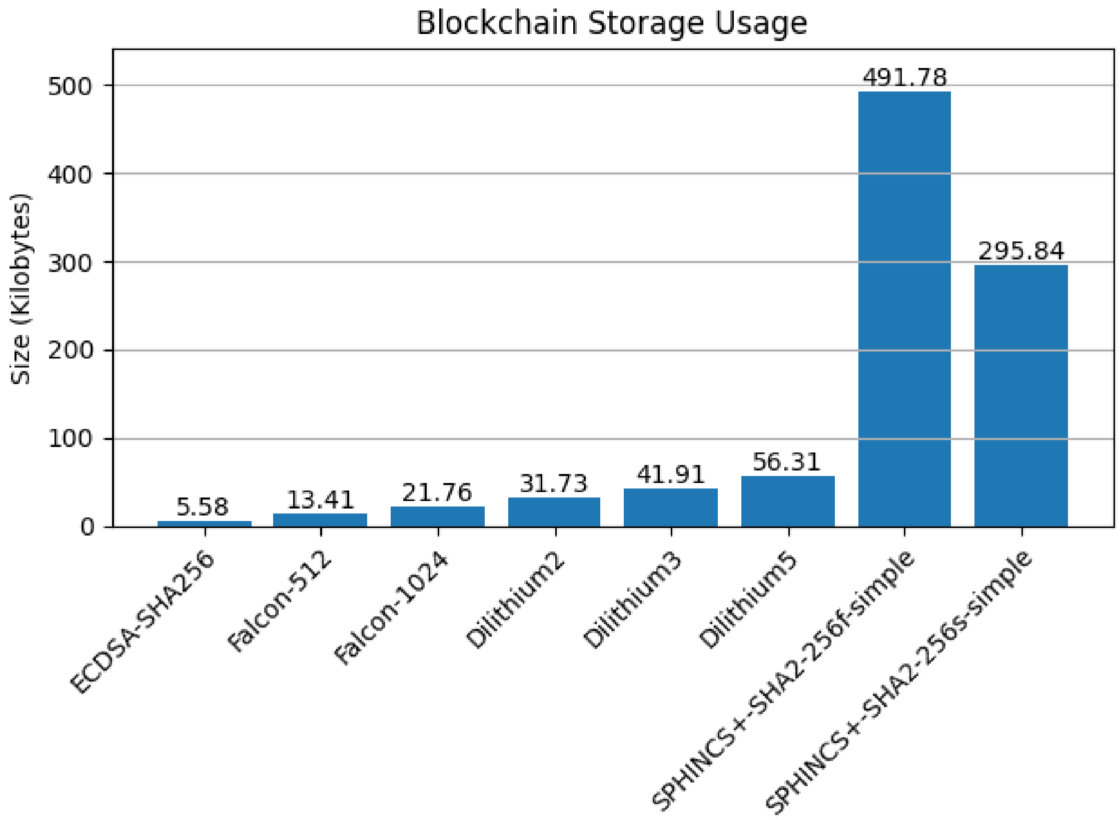
Signature Size

- Signature size increases blockchain's **storage requirements**
- Effects on transaction throughput



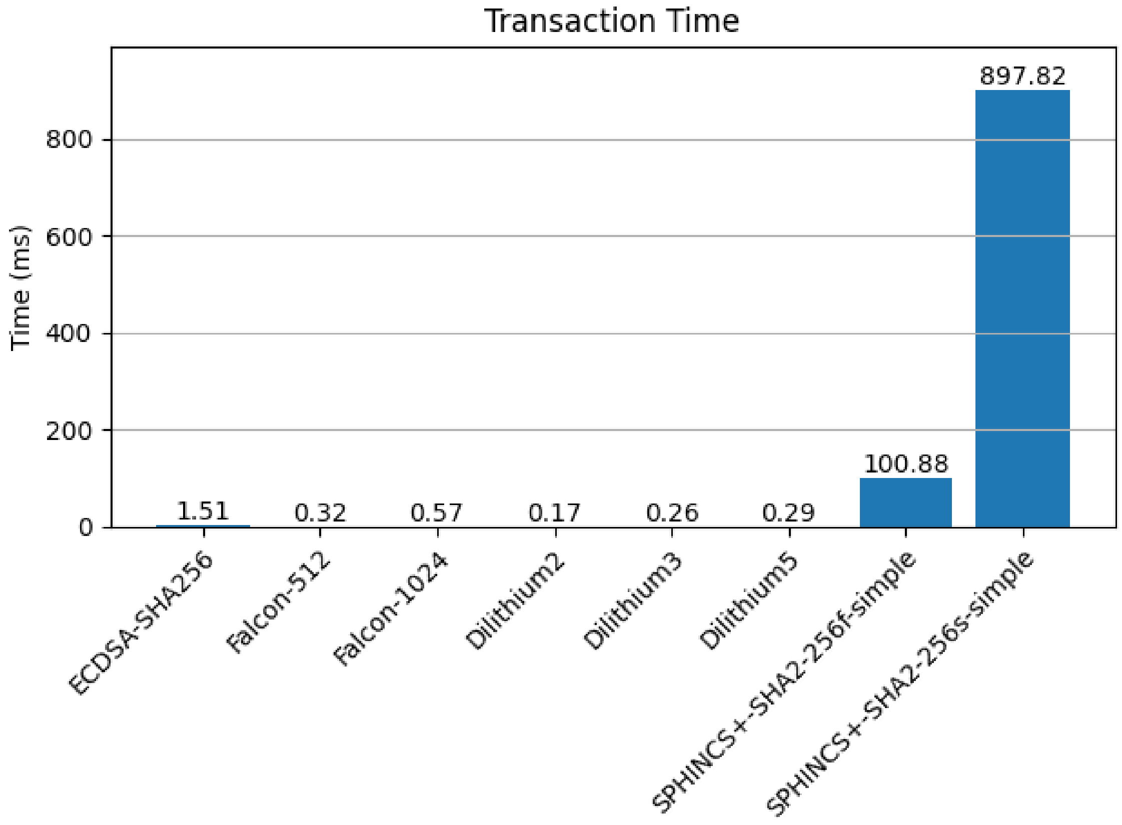
Blockchain Storage

- After 10 transactions
- Bloated blockchain sizes due to key/signature sizes for PQC
- Large storage requirements may lead to issues with **scalability** and **nodes' ability to store and synchronize** blockchain



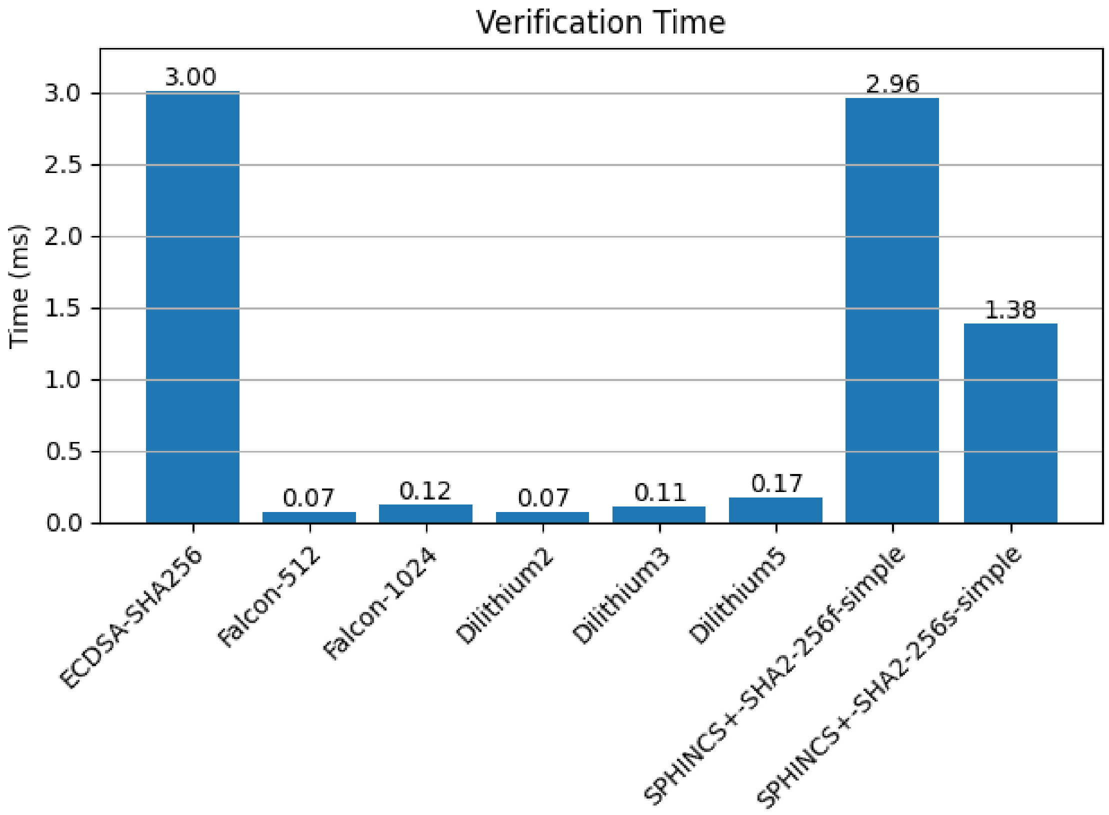
Transaction Time

- How long it takes to create and sign a transaction
- Longer transaction times could lead to slower confirmations and lower transaction throughput
- For blockchain systems that prioritize **speed and cost-effectiveness** (e.g., microtransactions, DeFi platforms), small transaction times are critical



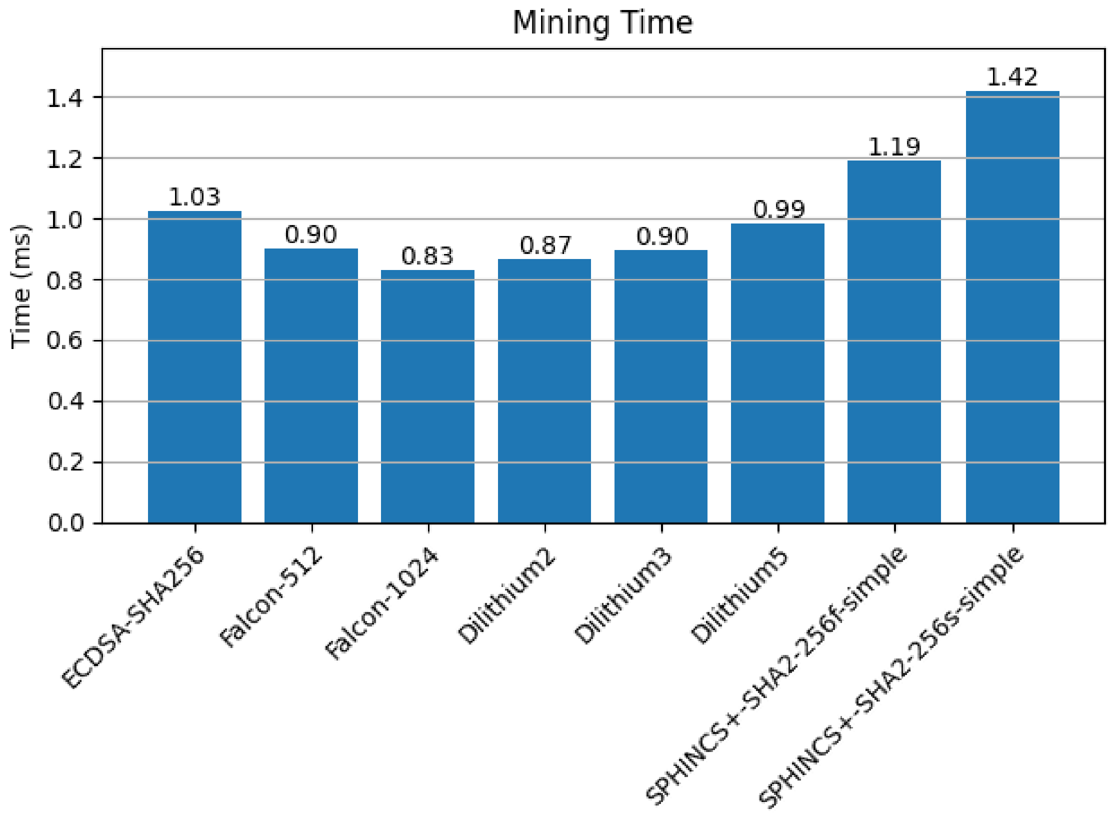
Verification Time

- How long it takes to verify a transaction
- Verification time affects **transaction throughput, block propagation and scalability**
- Faster transaction confirmation times enhances **usability**



Mining Time

- How long it takes to mine a transaction and add a new block
- Hashing algorithm, block size and difficulty are kept constant
- Possible variation due to signature size



Discussion

Falcon	CRYSTALS-Dilithium	SPHINCS+
+ • Compact signature sizes • Signing and verification efficiency	+ • Signing and verification efficiency • Moderate signature sizes	+ • Small public and private key sizes • Comparable verification time to ECDSA
- • Large public and private key sizes	- • Large public and private key sizes • Larger signature and storage than Falcon	- • Large signature sizes • Long transaction time • Large storage use

Discussion

Limitations

- Results are affected by Python implementation
- Lack of networking capabilities
- Small scale experiment

Future Directions

- Compare other quantum-safe algorithms
- Compare hashing algorithms
- Implement networking capabilities
- Experiment with block sizes and blockchain difficulties

Conclusion

- Post-quantum signatures face trade-off: **security vs key/signature size + storage**
- **Lattice-based algorithms** (Falcon, CRYSTALS-Dilithium) display great **signing and verification** efficiency
- SPHINCS+ (**hash-based**) suffers from **inefficiency + storage** despite small key size
- Future post-quantum integration is dependent on system requirements, long-term scalability, and evolution of computational resources
- Public and permissionless blockchains (e.g. Bitcoin, Ethereum) face greater challenges due to their open and decentralized nature