A Unified Yet Efficient Parallel Hardware Architecture for FrodoKEM

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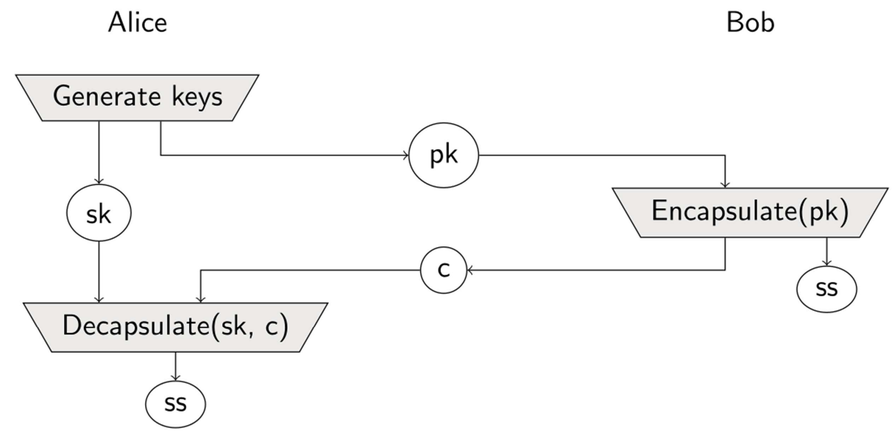
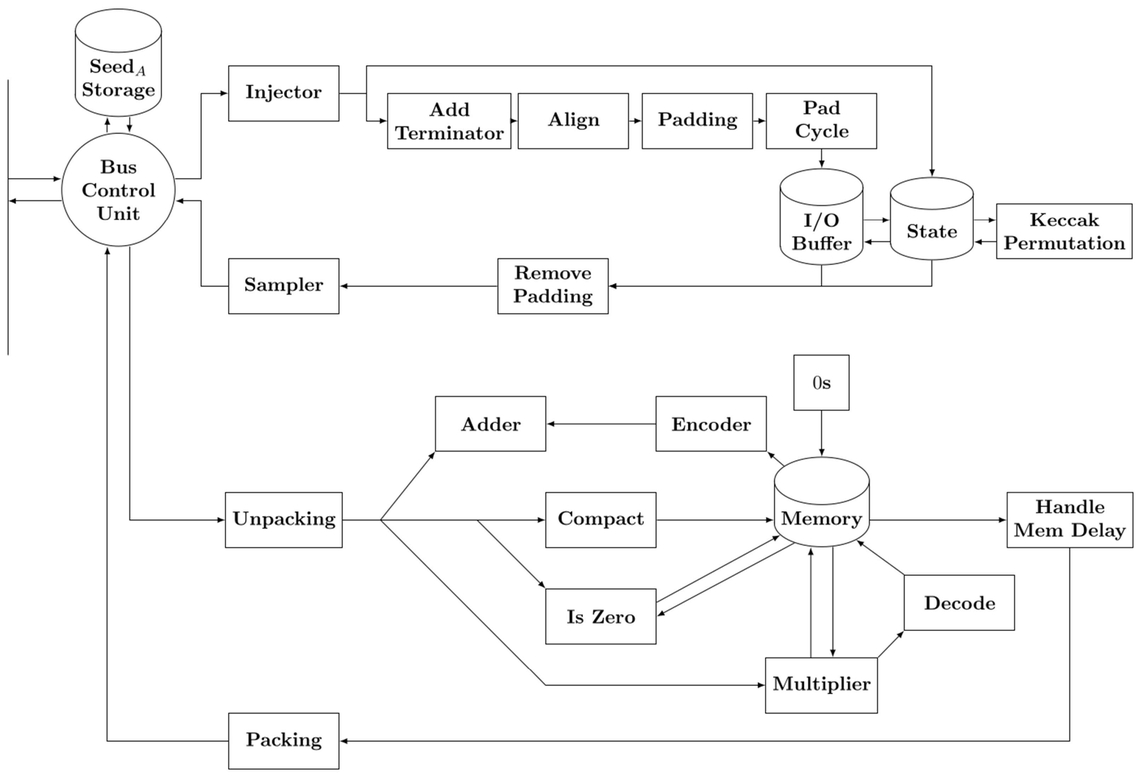
Why FrodoKEM?

- When quantum computers become available, Shor's Algorithm will break conventional public key cryptography we have been using
- FrodoKEM is a Post-Quantum Cryptography (PQC) algorithm to establish a shared secret [1]
  - Based on the unstructured lattice problem, which is generally considered to have a higher security margin than structured lattice
  - Not selected as standard by NIST, but this was not due to security problems [2], yet recommended by Germany [3], France [4], Netherlands [5], Turkey [6], etc.



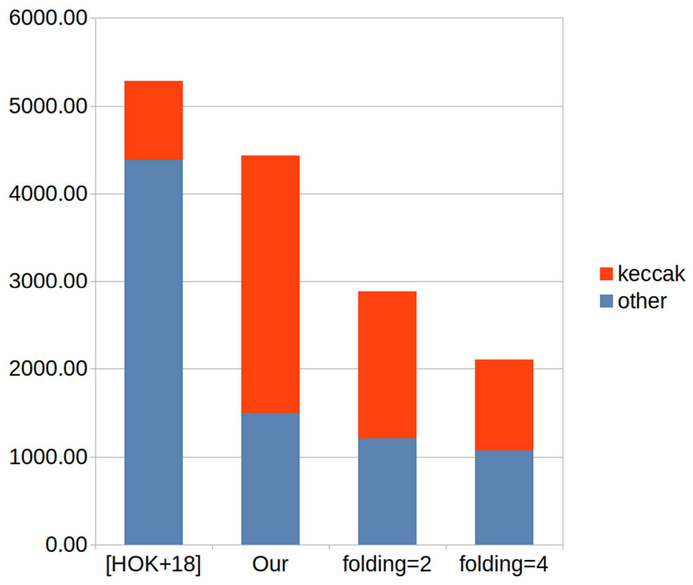
Key Encapsulation Mechanism (KEM)



Our module's overall architecture

Our existing implementation*

- A single module that can carry out **any FrodoKEM algorithm** (key generation, encapsulation, decapsulation) **with any parameter set** (640, 976, 1344), one operation at a time
- Our benchmark is [HOK+18]:
  - They provide 6 different modules each that carries out one specific operation
  - Our module is **overall** 14% smaller and 15x faster (than their largest module)
  - Our module is more flexible, as we can change operation and parameter set at run time



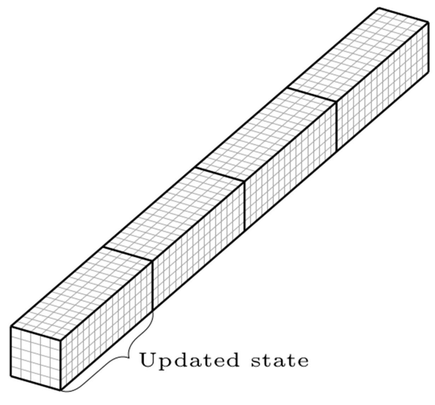
Comparison of existing results with estimates if we add folding to Keccak

Comparison of [HOK+18] and our current work*

- We use less area overall
- Yet our Keccak module is much bigger

<u>This is because our existing module does not use folding, and it executes a permutation per clock cycle</u>

n-folded Keccak implementation allows us to need only 1/n of the update logic, at the cost of being n times slower (needs n clock cycles to complete)



A folded implementation updates only a fragment of the state and shifts it every clock cycle

Comparison of speed and area of:

- Our current work* for different parameter set configurations
- [HOK+18], either for the decapsulation module (.D) or for a set of modules to have comparable functionality
- Our estimates for our planned next steps, using a folded Keccak implementation, for 2 and 4 folds

References

[1] https://frodokem.org/files/FrodoKEM_standard_proposal_20241205.pdf
[2] https://nvlpubs.nist.gov/nistpubs/ir/2022/NIST.IR.8413-upd1.pdf
[3] https://www.bsi.bund.de/SharedDocs/Downloads/EN/BSI/Publications/TechGuidelines/TG02102/BSI-TR-02102-1.pdf?__blob=publicationFile&v=9
[4] https://cyber.gouv.fr/sites/default/files/2022/04/anssi-avis-migration-vers-la-cryptographie-post-quantique.pdf
[5] https://www.ncsc.nl/binaries/ncsc/documenten/publicaties/2022/juli/guidelines-for-quantum-safe-transport-layer-encryption/guidelines-for-quantum-safe-transport-layer-encryption/Guidelines_for_PQC_-_Kyber_archief.pdf
[6] en.bilgem.tubitak.gov.tr/en/on-the-negative-effects-of-quantum-computers-on-secure-communication-and-actions-to-be-taken/

[HOK+18] 'Standard Lattice-Based Key Encapsulation on Embedded Devices' by James Howe, Tobias Oder, Markus Krausz, and Tim Güneysu. Published in TCHES 2018.

* Our existing work has been already presented at LightSEC 2025 and will be soon published as 'An Optimized FrodoKEM Implementation on Reconfigurable Hardware' by Springer. (Authors: Giuseppe Manzoni, Shekoufeh Neisarian and Elif Bilge Kavun)

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