Side-Channel Analysis of Post-Quantum Schemes

Julius Hermelink – Postdoc

July 8, 2025

Max Planck Institute for Security and Privacy

Who am I?

Julius Hermelink

Short CV:

- Postdoc at MPI-SP in Bochum.
- PhD from UniBw in Munich in 2024.
- Master's in Mathematics from LMU in 2020.

Research interests:

- Implementation attacks on post-quantum schemes.
- Soft-analytic side-channel attacks.
- Cryptanalysis (under side information).
- Information theory.
- How (not) to use formal methods for side-channel security.

The Quantum Threat

Quantum computers threaten currently used asymmetric cryptography.

We have to assume that:

- Large-scale quantum computer break commonly used asymmetric schemes.
- Adversaries: harvest now, decrypt later.

IBM Research, https://www.flickr.com/photos/ibm_research_zurich/51248690716/, unmodified, license: CC BY 2.0

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Therefore, we need:

- Post-quantum asymmetric cryptography.
- Most pressingly key exchanges.

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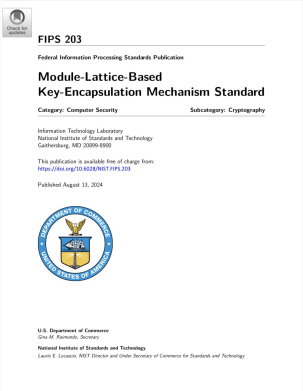
The NIST Standardization Process

NIST is in the process of standardizing post-quantum cryptography.



FIPS 203

Federal Information Processing Standards Publication

Module-Lattice-Based Key-Encapsulation Mechanism Standard

Category: Computer Security — Subcategory: Cryptography

Information Technology Laboratory
National Institute of Standards and Technology
Gaithersburg, MD 20899-8900

This publication is available free of charge from:
https://doi.org/10.6028/NIST.FIPS.203

Published August 13, 2024

U.S. Department of Commerce
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- Five candidates already selected.
- Three are lattice-based.
- ML-KEM and ML-DSA standardized.

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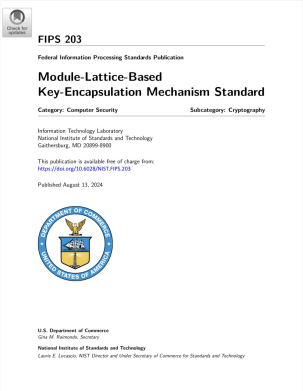

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ML-KEM used in Signal, Chrome, iMessage, ...

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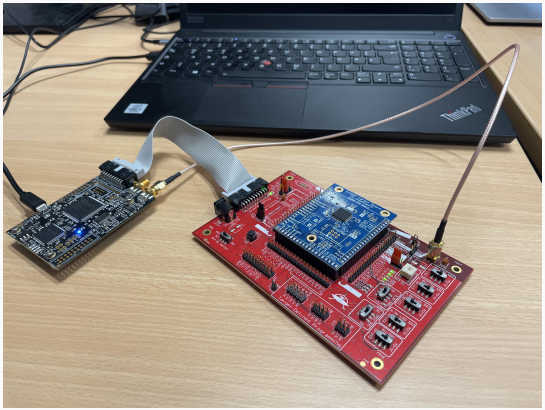

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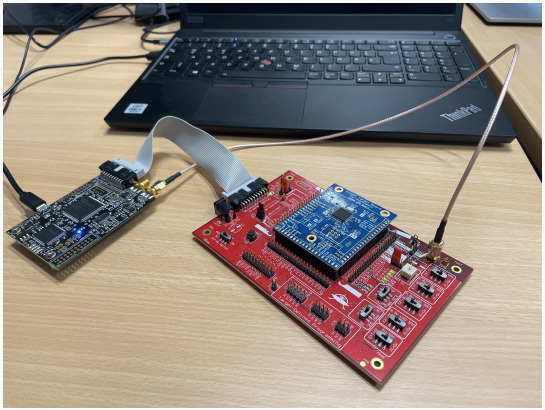

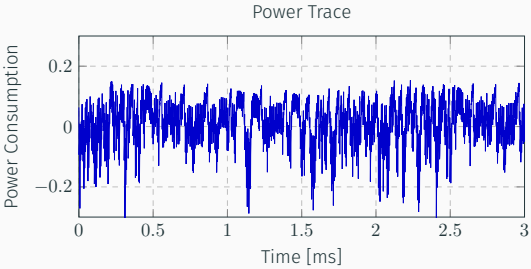

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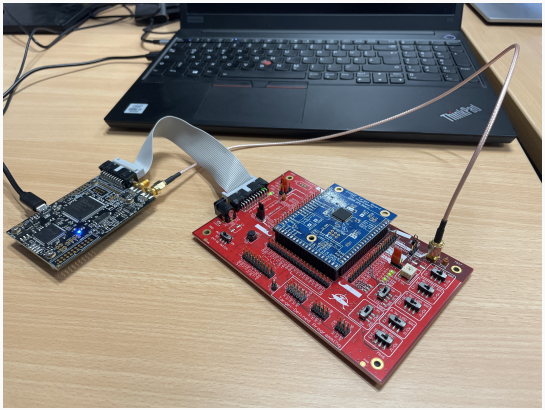
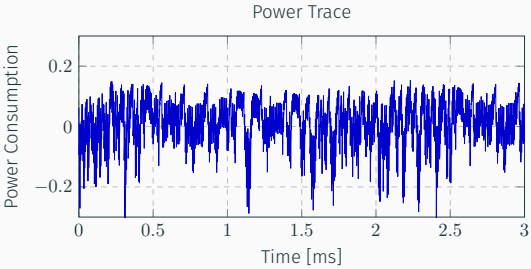
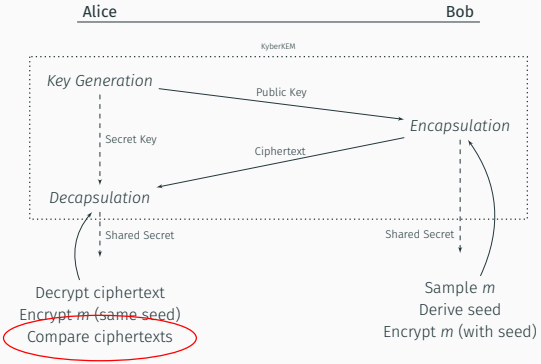




Lattice-based schemes/post-quantum cryptography comes with different challenges.

New Standards, New Challenges



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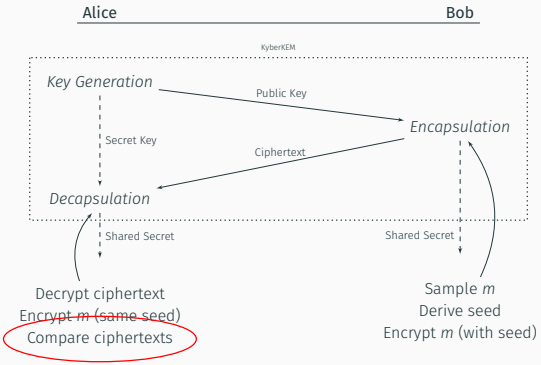

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- Comparison $\mathtt{ct}' == \mathtt{ct}$.
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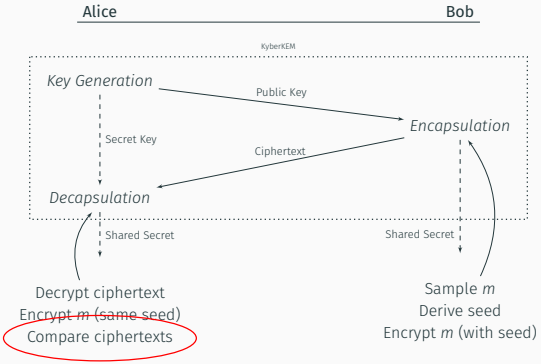

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$$(-1)^{\mathtt{obs}}(\mathbf{r}^\top \mathbf{e} - \mathbf{s}^\top(\mathbf{e}_1 + \Delta\mathbf{u}) + e_2 + \Delta v) \leq 0$$

Julius Hermelink, Erik Mårtensson, Simona Samardjiska, Peter Pessl, and Gabi Dreo Rodosek. "Belief Propagation Meets Lattice Reduction: Security Estimates for Error-Tolerant Key Recovery from Decryption Errors". In: *IACR Transactions on Cryptographic Hardware and Embedded Systems* 2023.4 (2023), pp. 287–317

Most Recent Secure Proposal

Recent secure proposal: we suspected signal amplification.

Julius Hermelink, Kai-Chun Ning, Richard Petri, and Emanuele Strieder. "The Insecurity of Masked Comparisons: SCAs on ML-KEM's FO-Transform". In: *ACM CCS 2024: 31st Conference on Computer and Communications Security*. Ed. by Bo Luo, Xiaojing Liao, Jun Xu, Engin Kirda, and David Lie. ACM Press, Oct. 2024, pp. 2430–2444

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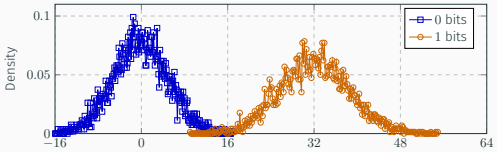

Power consumption of processing a single shared bit.

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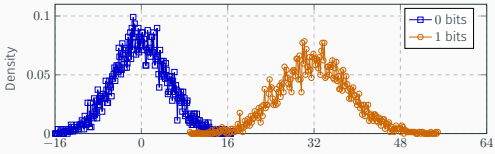

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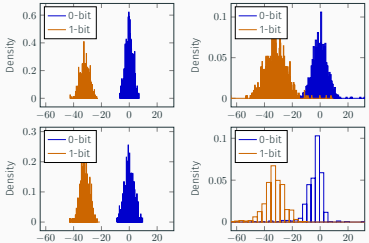
Actual leakage confirms our model:



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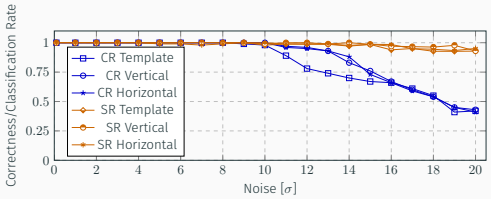
Highly Noise-Tolerant Attacks

Leads to highly noise-tolerant attacks.

Simulated results with 4 shares:



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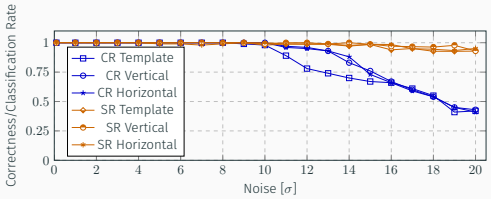

Why do these attacks work so well?

- Slight advantage enough.
- Amplified leakage.

$\rightarrow$ High noise requirements
– analysis in [HFG+25].

Noise/masking order necessary to prevent attacks extraordinarily high.

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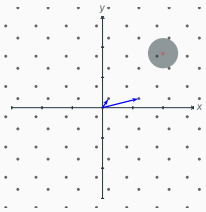
Side Information in Lattice-Based Schemes

How to deal with side information in lattice-based schemes?

Primal attack:
E.g., [DDGR20; DGHK23; MN23]



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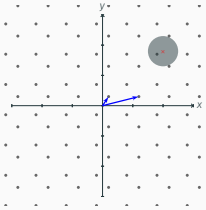
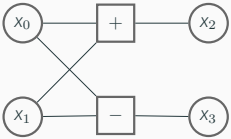


Soft-analytic [VGS14]:
E.g., [PPM17; tPP21; BAE+24]



Attacks: often noisy information on Hamming weights.

Distribution Hints

Various proposals to define and deal with side information.

Previous hint definitions [DDGR20; DGHK23]:

For known $\mathbf{v}, l, k$:

- $\langle \mathbf{v}, \mathbf{x} \rangle = l$
- $\langle \mathbf{v}, \mathbf{x} \rangle = l \mod k$
- $\langle \mathbf{v}, \mathbf{x} \rangle = l + \mathcal{N}$
- $\langle \mathbf{v}, \mathbf{x} \rangle \leq l$
- short $\mathbf{v} \in \Lambda$

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Information from [RPJ+24] without loss!

$$\mathrm{HW}(\langle \mathbf{v}, \mathbf{x} \rangle) \sim \mathcal{D}$$

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Solving Distribution Hints

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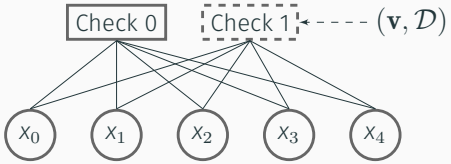

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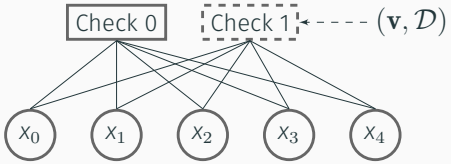

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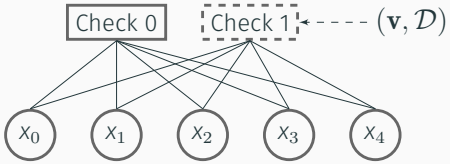

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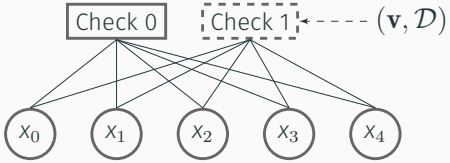

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Change scores for coefficients j:

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and perform k best updates on guess $\mathbf{x}'$.

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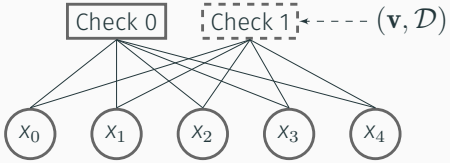

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Side-Channel Attacks on Masked ML-DSA

A more conceptual approach to side-channel attacks on ML-DSA.

Masked ML-DSA:

- Different types of masking.
- Choice of signed and unsigned integers.
- Several attacks on unmasked ML-DSA.

How to target masked ML-DSA?

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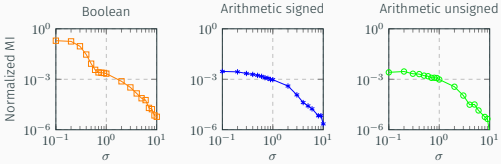
How to target masked ML-DSA?

Mutual information per measurement:



Julius Hermelink, Kai-Chun Ning, and Richard Petri. *Finding and Protecting the Weakest Link: On Side-Channel Attacks on Masked ML-DSA*. Cryptology ePrint Archive, Report 2025/276 (To Appear at Crypto 2025). 2025. URL: https://eprint.iacr.org/2025/276

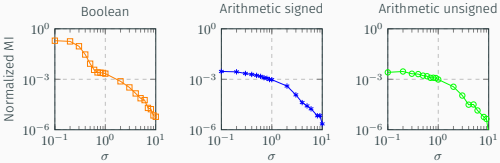
A more conceptual approach to side-channel attacks on ML-DSA.

Masked ML-DSA:

- Different types of masking.
- Choice of signed and unsigned integers.
- Several attacks on unmasked ML-DSA.

How to target masked ML-DSA?

Mutual information per measurement:



Our framework can be applied with hint-filtering technique.

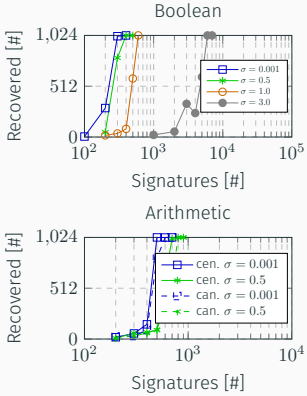
Julius Hermelink, Kai-Chun Ning, and Richard Petri. *Finding and Protecting the Weakest Link: On Side-Channel Attacks on Masked ML-DSA*. Cryptology ePrint Archive, Report 2025/276 (To Appear at Crypto 2025). 2025. URL: `https://eprint.iacr.org/2025/276`

Targeting ML-DSA

First attacks against masked ML-DSA targeting $\mathbf{y}$ in several representations.

Practical attacks:

- Replicates previous attack.
- New reasonably noise-tolerant second-order attacks.
- Concrete practical recommendations for future implementation.



Julius Hermelink, Kai-Chun Ning, and Richard Petri. *Finding and Protecting the Weakest Link: On Side-Channel Attacks on Masked ML-DSA*. Cryptology ePrint Archive, Report 2025/276 (To Appear at Crypto 2025). 2025. URL: `https://eprint.iacr.org/2025/276`

Conclusion

Conclusion:

- Protecting ML-KEM is challenging.
- Efficient and generic framework.
- Attacks on masked ML-DSA.
- Works well with info-theoretic analysis.
- Framework applies more generally.

Open source:

Easy to use!

```
bp = PyBP(vs, distributions)
greedy = PyGreedy(vs, distributions)
greedy.set_nthreads(4)
bp.set_nthreads(4)

greedy.solve(k)
guess = greedy.get_guess()
bp.propagate()
dists = bp.get_results()
```

Thank you for your attention!

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