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Practical Side-Channel and Fault Injection Analysis on Lattice-Based Cryptography

Prasanna Ravi

under supervision of

Dr.Anupam Chattopadhyay

Dr.Shivam Bhasin

Temasek Labs and School of Computer Science and Engineering, NTU, Singapore

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IN THE NOT TOO DISTANT FUTURE…

Security in Quantum Era: NIST PQC Call

- **National Institute of Standards and Technology (NIST)** initiated a standardization process for post-quantum cryptography (**PQC**) in November 2017.
- The first round had **69** candidates, second round had **26** candidates and the process is currently in its **third** and **final** round [AGJS+20].

Type	Signature	PKE/KEM	Finalist (Alternate)
Lattice Based	**2**	**3 (2)**	**5 (2)**
Code-Based	-	1 (2)	1 (2)
Multivariate	1 (1)	-	1 (1)
Hash-Based	- (2)	-	- (2)
Isogeny based	-	- (1)	- (1)
Others	-	-	- (0)
Total	3 (3)	4 (5)	7 (8)

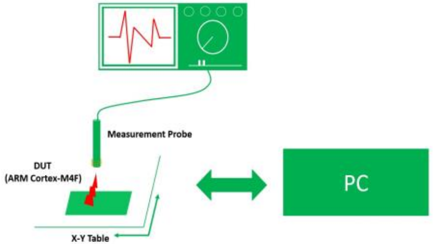
Security in Quantum Era: NIST PQC Call

- **Selection Criteria for Standardization Process:**
  - Theoretical Post-Quantum Security Guarantees
  - Implementation Performance (Speed, Area, latency, Power) on various HW/SW platforms
  - **Resistance against Side-Channel Attacks (SCA) and Fault Injection Attacks (FIA)**

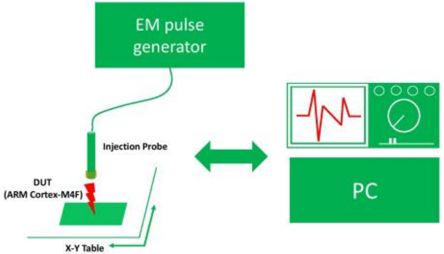
- NIST explicitly states that "*encourages additional research regarding side-channel analysis*" of the finalist candidates and that it "*hopes to collect more information about the costs of implementing these algorithms in a way that provides resistance to such attacks*" [AGJS+20].

Main Focus:

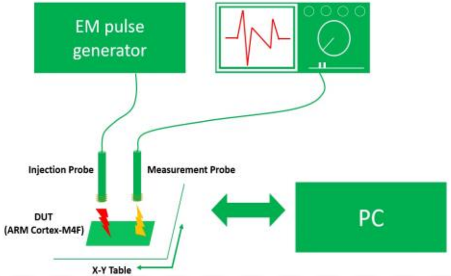
Side-Channel Analysis (SCA)

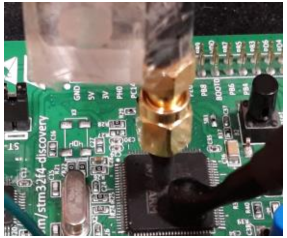


Fault Injection Analysis (FIA)



Combined SCA and FIA





Research Outcomes

Lattice-based Cryptography

Physical Attacks

SCA

[**R**RBC20] (*TCHES 2020*)

[**R**BRC20]** (*IACR ePrint*)

[**R**EBCR21] (*Third NIST PQC Conference*)

FIA

[**R**RBCM19] (*COSADE 2019*)

[**R**JHCB19] (*AsiaCCS 2019*)

Combined SCA and FIA

[**R**BRC20] (*IACR ePrint*)

Survey

[**R**HCB20]
(ACM Computing Surveys)

Implementations

Countermeasures

[**R**PBC20] (*SPACE 2020*)

Optimizations

[**R**GCB19] (*CARDIS 2019*)

[**R**SCBE20] (*ISCAS 2020*)

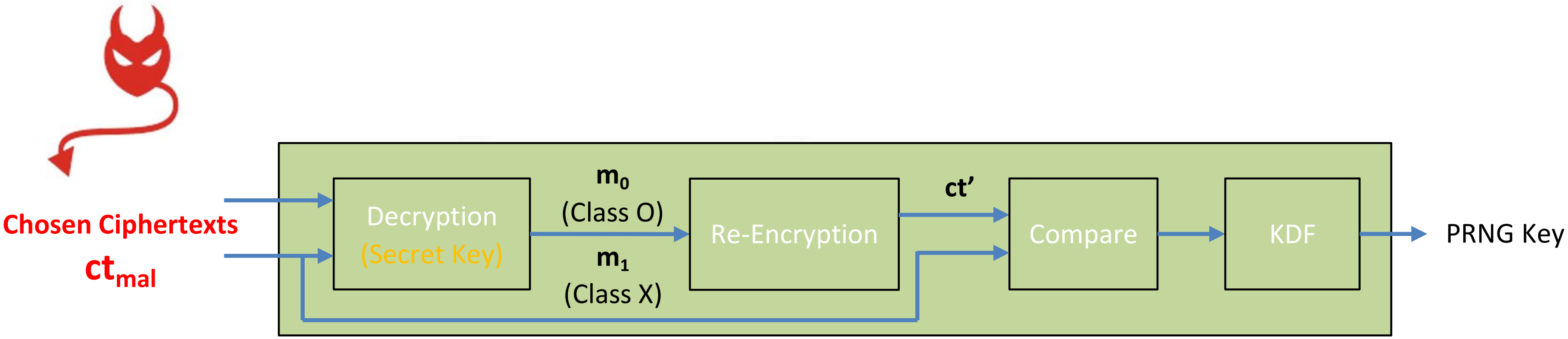
**** Under Submission**

Main Contributions

Side-Channel Analysis (SCA)

- **Attack Scenario:** Chosen-Ciphertext Attacker (CCA)
- **Attack Target:** CCA secure PKE and KEMs for key recovery, message recovery

- *A Chosen Ciphertext Attacker in the presence of side-channels can perform a variety of message recovery and key recovery attacks.*



IND-CCA Secure Decapsulation

Side-Channel Analysis (SCA)

- **PC Oracle-based SCA** in LWE/LWR-based schemes (***TCHES 2020***):
  - Novel EM/power side-channel vulnerabilities to realize a PC Oracle
  - Key Recovery in a few thousand queries
  - No. of target schemes: **six** (**Kyber**, **Saber**, **Frodo**, NewHope, Round5 and LAC)

- **FD Oracle-based SCA** in LWE/LWR-based schemes (***IACR ePrint*****):
  - Novel **single trace** message recovery attacks
  - Exploiting **Ciphertext Malleability** as a powerful tool to aid SCA
  - Break well-known shuffling and masking countermeasures
  - No. of target schemes: **six** (**Kyber**, **Saber**, **Frodo**, NewHope, Round5 and LAC)
  - First practical combined SCA and FIA over lattice-based schemes

- **PC and DF Oracle-based SCA** in NTRU-based schemes (***Third NIST PQC Conference***):
  - Target Scheme: Streamlined NTRU Prime
  - Key Recovery in a few thousand queries

**** Under Submission**

Side-Channel Analysis (SCA)

Side-Channel Assisted Chosen Ciphertext Attacks

- **LWE/LWR-based**
  - **PC Oracle-based**
    - D'Anvers et al. [DTVV19]
    - Ravi et al. [RRBC20]
  - **FD Oracle-based**
    - Xu et al. [XPRO20]
    - Ravi et al. [RBRC20]
    - Ngo et al. [NDGJ21]
  - **DF Oracle-based**
    - Guo et al. [GJN20]
    - Bhasin et al. [BDH+21]
- **NTRU-based**
  - **PC Oracle-based**
    - Ravi et al. [REBCR21]
  - **DF Oracle-based**
    - Ravi et al. [REBCR21]

Fault Injection Analysis (FIA)

- **Fault Injection Analysis:**
  - Forcing **Nonce-Misuse** through Faults (***COSADE 2019***):
    - First practical FIA (EM-based) over lattice-based schemes
    - No. of target schemes: **four** (Kyber, Dilithium, Frodo and NewHope)
    - Countermeasure incorporated into algorithmic specification of Frodo (Alternate Finalist)
  - Exploiting **Determinism** in Lattice-based Signatures (***AsiaCCS 2019***):
    - Fault Attack + Forgery using partial secret key recovery
    - First practical FIA (EM-based) over **two** signature schemes (Dilithium and qTESLA)

Implementations and Countermeasures

- Configurable SCA Countermeasures for Number Theoretic Transform (***SPACE 2020***):
  - Novel **masking** and **shuffling** countermeasures
  - Practical Implementation within Kyber and Dilithium on the ARM Cortex-M4

- Improving Speed of Dilithium's Signing Procedure *(**CARDIS 2019**):*
  - 8-35% improvement in signing speed of Dilithium on ARM Cortex-M4

- PQC Evaluation within Authentication Protocol in Automotive Context (***ISCAS 2020***):
  - Integration of lattice-based schemes within an authentication protocol LASAN.
  - Practical Evaluation on Automotive testbed based on ARM Cortex-R4 MCU (RTOS-based)
  - **Communication Bandwidth** is a main bottleneck in implementing PQC for automotive networks

“In a way, these things are like gold nuggets that God left in the forest. If I'm walking along in the forest and I stubbed my toe on it, who's to say I deserve credit for discovering it?”

-- Dr. Martin Hellman on the discovery of Public-Key Cryptography

Thank you!

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