Update on the Performance and Mode-level Properties of ISAP

Christoph Dobraunig, Maria Eichlseder, Stefan Mangard, Florian Mendel, **Bart Mennink**, **Robert Primas**, Thomas Unterluggauer

NIST LWC Workshop 2022

Outline

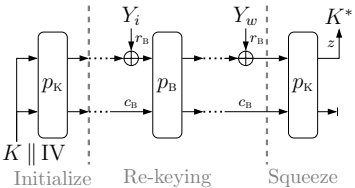
- Mode-level Properties
- Implications on Physical Attacks

Mode-level Properties

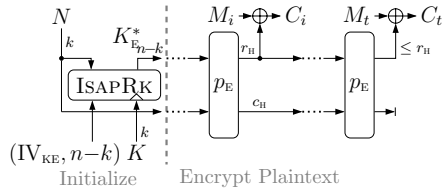
ISAP

- Sponge/duplex-based authenticated encryption mode
- Instantiation:
  - ASCON-p
  - KECCAK-p [400]
- Carefully selected capacities and rates:
  - Robustness against DPA
  - Hardening against fault attacks: DFA, SFA, SIFA

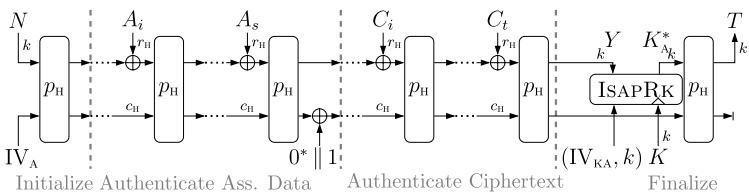
Isap



IsapRK

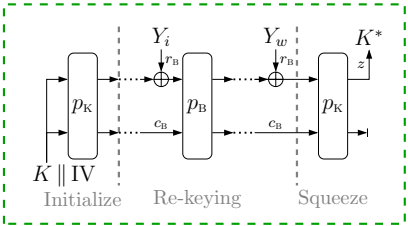


IsapEnc



IsapMAC

ISAP



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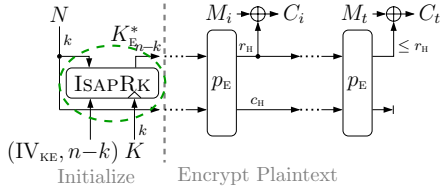

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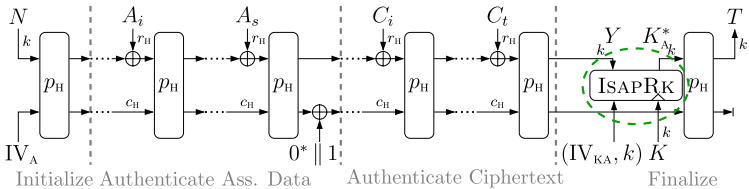

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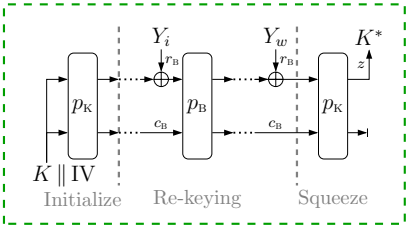

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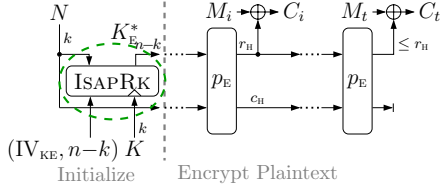

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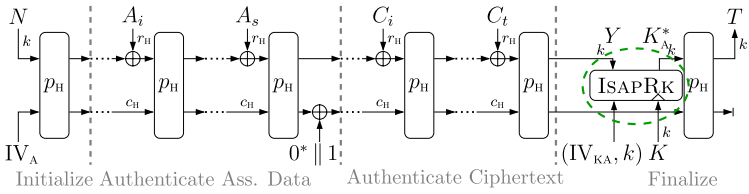

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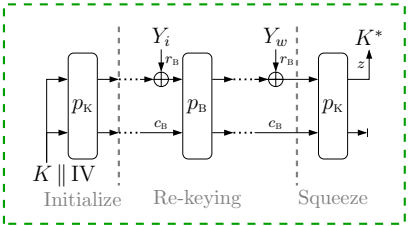

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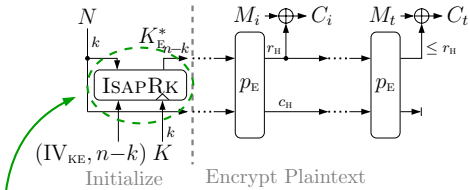

ISAPENC

pseudorandom subkeys

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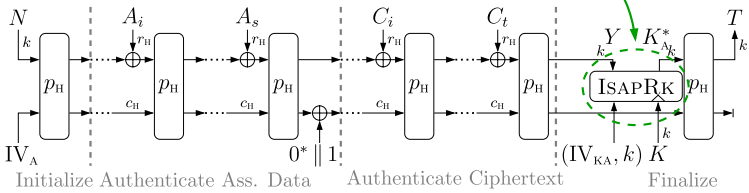

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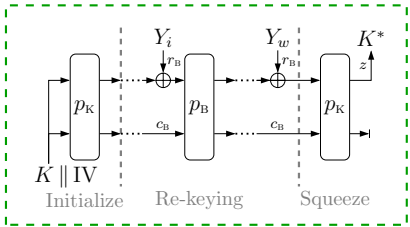

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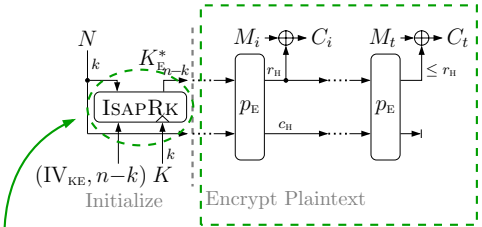

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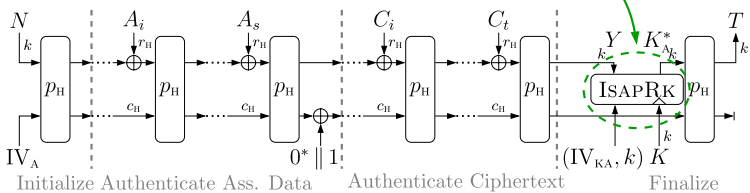

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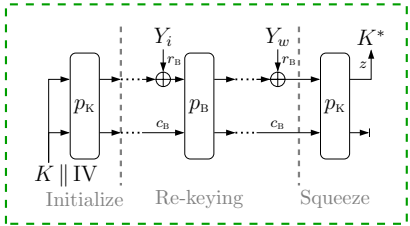

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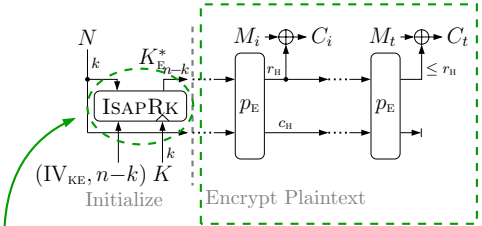

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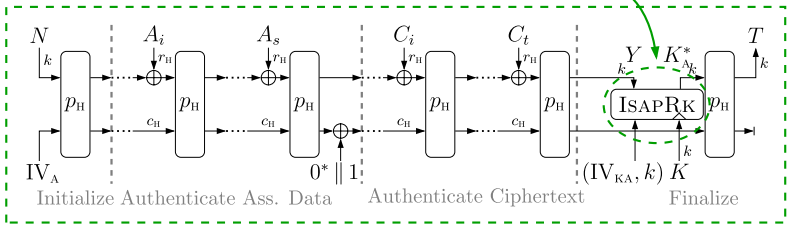

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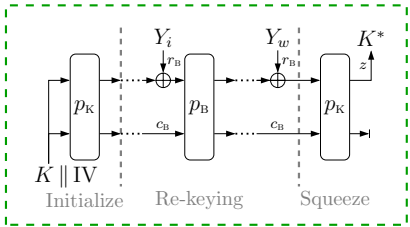
SuKS hashes at high rate

Leakage Resilience of ISAP Mode



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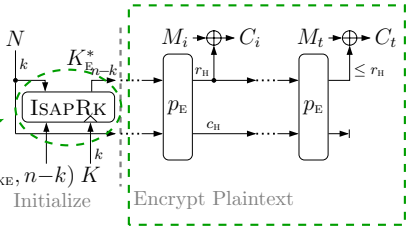

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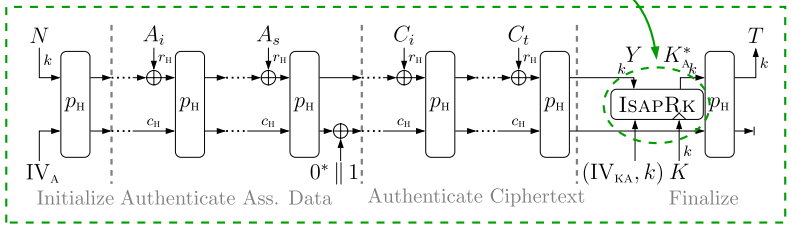

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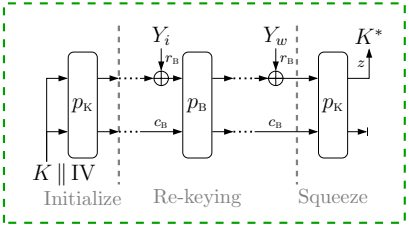

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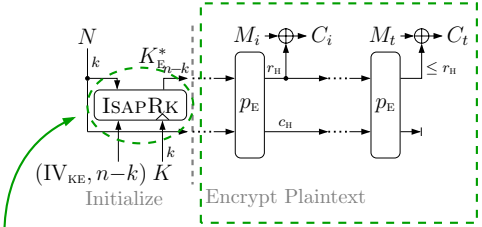

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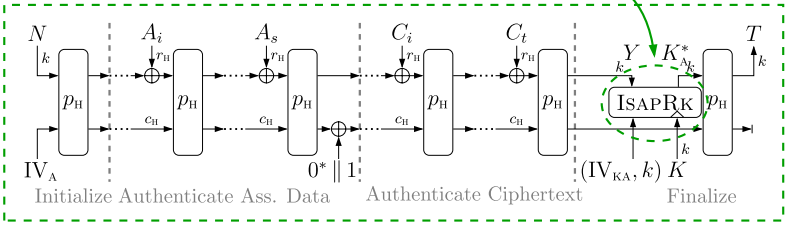

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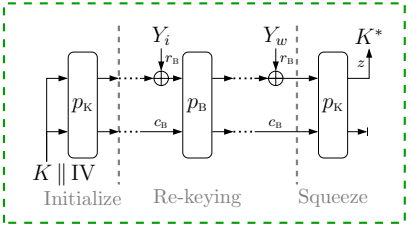

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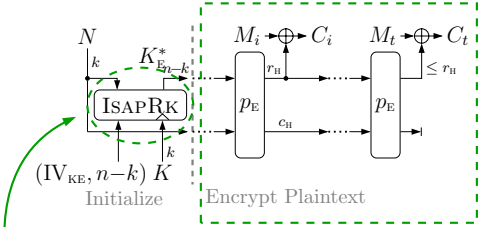

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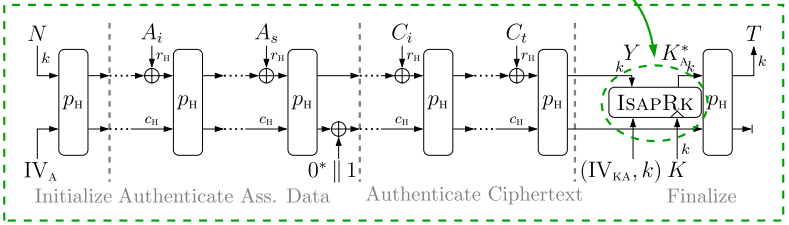

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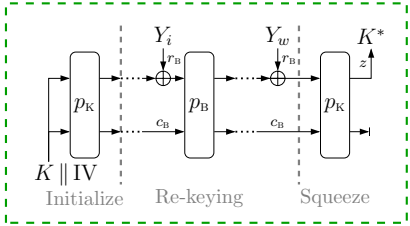

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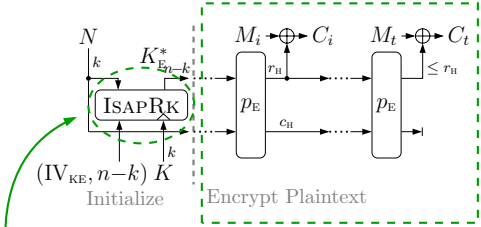

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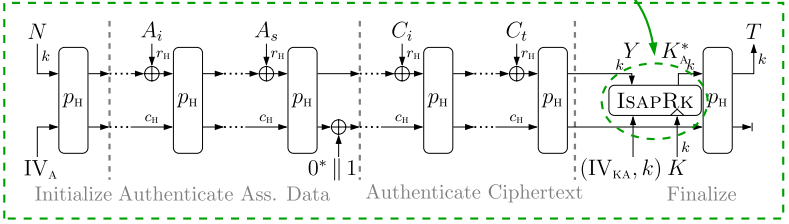

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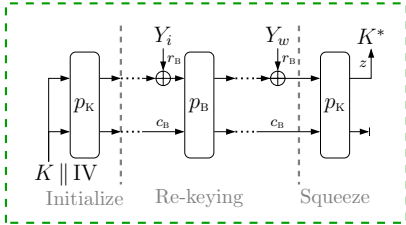

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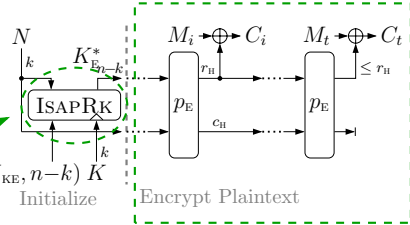

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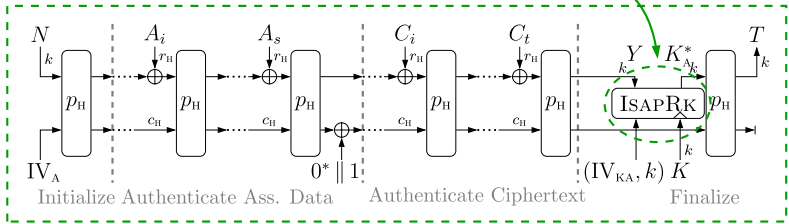

ISAPMAC

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Summary of Conventional Security

- Security of ISAP in nonce-respecting setting
  - Assumption: random permutation model, bounded leakage model
  - ISAP is a secure authenticated encryption scheme [DEM+20]
- Exotic features
  - Security of nonce-reuse: leakage-resilient authenticity preserved!
  - Release of unverified plaintext: security guaranteed due to EtM
  - Key-committing security: usage of ISAPRK within ISAPMAC

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Two New Leakage Resilience Results

EUROCRYPT 2021 [DM21]

Leakage Resilient Value Comparison With Application to Message Authentication

Christoph Dobraunig and Bart Mennink

- Solution to perform tag verification …
  - in a leakage resilient way
  - without extra primitives

In submission [DMP20]

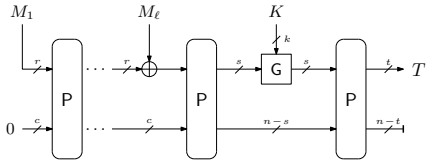
Leakage and Tamper Resilient Permutation-Based Cryptography

Christoph Dobraunig and Bart Mennink and Robert Primas

- More practical leakage resilience model
  - closer fit to actual leakage
  - also captures fault attacks

Leakage Resilient Value Comparison (LRVC)

- SuKS (Suffix Keyed Sponge):



- Naive Tag Verification on input of message/tag tuple $(M, T^\star)$:
  - Compute $T = \mathsf{SuKS}(K, M)$
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- Verification might leak information about T!
- This work: formal analysis of leakage resilient value comparison

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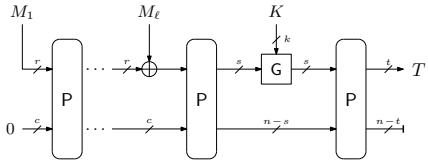

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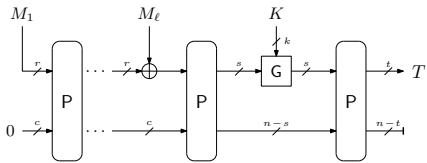

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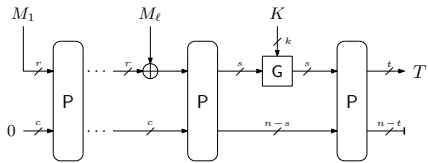

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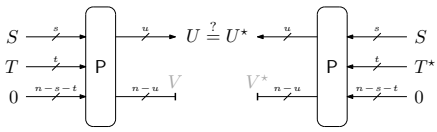
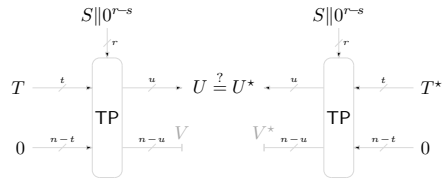
LRVC: (Tweakable) Permutation-Based Value Processing



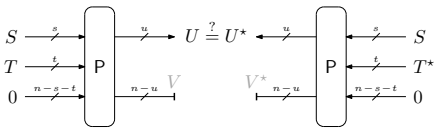
PVP



TPVP

- PVP gives leakage resilient value comparison
  - P is public or secret permutation
  - Similar to earlier suggestion of designers of ISAP [DEM+20]
- TPVP gives leakage resilient value comparison
  - TP is public or secret tweakable permutation
  - TPVP with secret tweakable permutation was used in Spook [BBB+20]

LRVC: (Tweakable) Permutation-Based Value Processing



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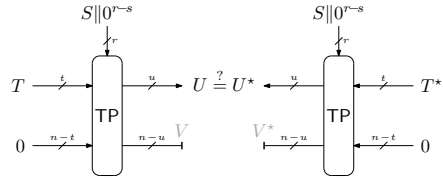

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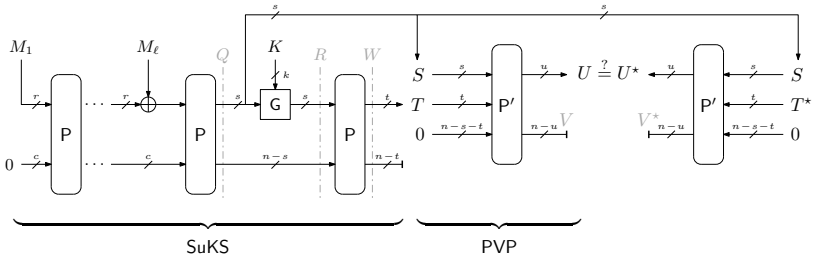
LRVC: SuKS-then-PVP (StP)



- Natural combination of SuKS and PVP
- Salt taken from keyless computation of SuKS
- Leakage resilience of StP (and thus of Isap) follows from that of SuKS and of PVP

Accumulated Interference

- Previous analysis in bounded leakage model
  - Adversary can choose any polynomial-time computable leakage function with bounded range [DP08]
  - Each new primitive call leaks $\leq \lambda$ bits
- This work: Accumulated Interference
  - We do not have to bound leakage per primitive call a priori
  - Rather, define it as the Accumulated Gain over time: $\mathrm{AG}(i)$
  - A priori and a posteriori, accurate bound on $\mathrm{AG}(i)$ derived through measurements
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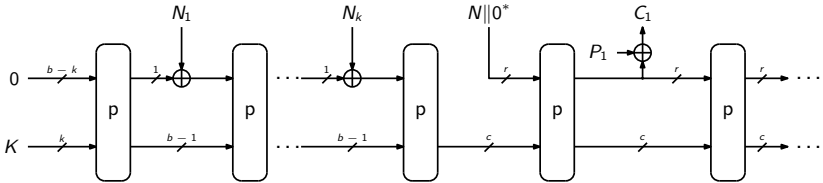
Accumulated Interference: ASAKEY

- We showcase the power of Accumulated Interference in ASAKEY



- ASAKEY $\approx$ encryption part of ISAP
- ASAKEY is a LR-PRF up to (simplified) bound $\sum_{i=1}^{P} \frac{Q}{2^{b-\mathrm{AG}(i)-\tau}}$
- Naive (a priori) bounding: $\mathrm{AG}(i) \leq i \cdot \lambda$
- More accurate bounding using simulations

Implications on Physical Attacks

Mode-level Robustness Claims of ISAP

- Protection against Differential Power Analyis (DPA)
  - DPA-based key recovery $\rightarrow$ AI
  - DPA-based plaintext recovery
  - Optional: DPA-based tag recovery $\rightarrow$ STP
- Protection against Statistical (Ineffective) Fault Analysis (SFA/SIFA) $\rightarrow$ AI
- Hardening against Differenial Fault Analysis (DFA)
- Hardening against Profiling/Simple Power Analysis (SPA)

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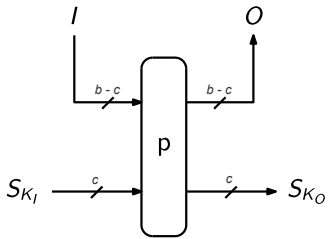
DPA-based Key Recovery

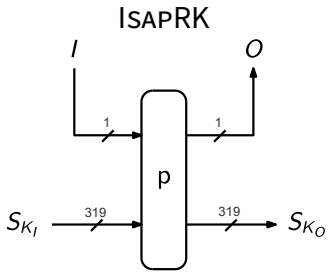
- Attack:
  - Query a keyed primitive using multiple different inputs
  - Hypothesis tests with corresponding power traces and sub-key guesses
- ISAP processes the main key only during ISAPRK
- ISAPRK limits amount of different queries to primitive with same key to 2

Accumulated Interference: Estimating $\mathrm{AG}_{\mathtt{atk}}(\boldsymbol{X}, \boldsymbol{q}, r)$



- $\mathrm{AG}_{\mathtt{atk}}(\boldsymbol{X}, \boldsymbol{q}, r)$
  - $\mathtt{atk} \in \{\mathtt{spa}, \mathtt{dpa}, \mathtt{sfa}, \ldots\}$
  - $\boldsymbol{X}$ inputs to p
  - $\boldsymbol{q}$ evaluation of p per input
  - r maximal number of X_i with the same inner part

Accumulated Interference: Estimating $\mathrm{AG}_{\mathtt{atk}}(\boldsymbol{X}, \boldsymbol{q}, r)$



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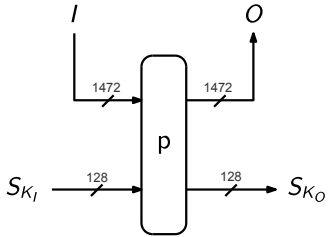
Accumulated Interference: Estimating $\mathrm{AG}_{\mathtt{atk}}(\boldsymbol{X}, \boldsymbol{q}, r)$

Our analysis [DMP20]



- $\mathrm{AG}_{\mathtt{atk}}(\boldsymbol{X}, \boldsymbol{q}, r)$
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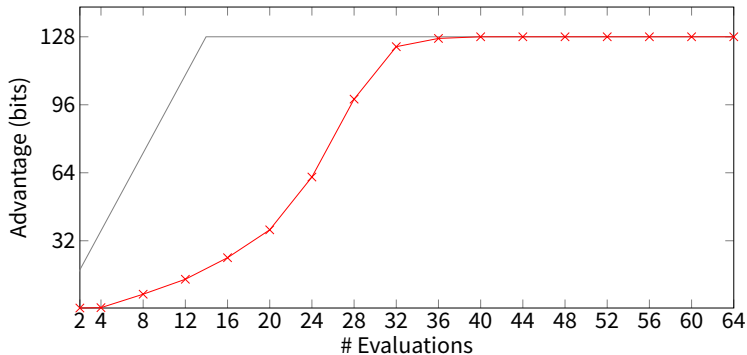
Accumulated Interference: Estimating $\mathrm{AG}_{\mathrm{dpa}}(\boldsymbol{X}, \boldsymbol{q}, r)$



Evaluation Setup: Chipwhisperer-Lite with XMEGA128D4 target [DMP20]

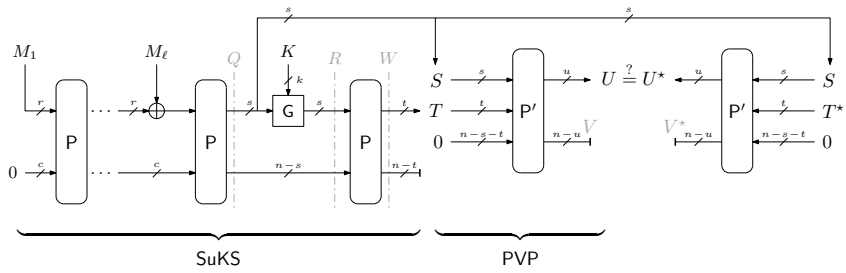
DPA-based Plaintext Recovery

- Attack:
  - Query the decryption with a constant nonce and varying ciphertexts
  - Constant key stream is combined with varying ciphertext blocks
  - Simple DPA-style attack can reveal the key stream
- Such attacks do not require direct extraction of cryptographic keys
- Firmware updates: Plaintext could carry cryptographic keys or IP
- ISAP's two-pass construction prevents this scenario
  - Tag verification before start of decryption

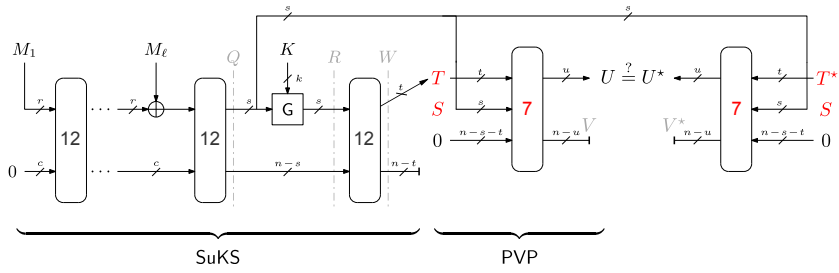
DPA-based Tag Recovery

- Attack:
  - Given a correct ciphertext C, flip some bits leading to related $C_1 \ldots C_n$, that then correspond to related messages $M_1 \ldots M_n$
  - These can then be used to forge valid tags for $C_1 \ldots C_n$ due to leaks in tag comparison [BBC+20]
- Tag comparison needs protection
  - Algorithmic masking: 127 ANDs with mult. depth of 7 (128-bit tag)
  - On mode-level: SuKS-then-PVP (STP)

SuKS-then-PVP (STP)

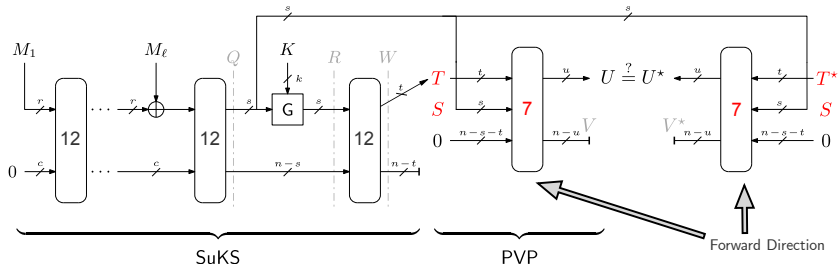


SuKS-then-PVP (StP)



- Our instantiation of StP at the end of IsapMAC (of Isap-A-128a):
  - 14 additional permutation rounds for tag comparison
  - No noteworthy increase in code-size/area
  - No changes to Isap algorithm and cryptographic properties

SuKS-then-PVP (StP)



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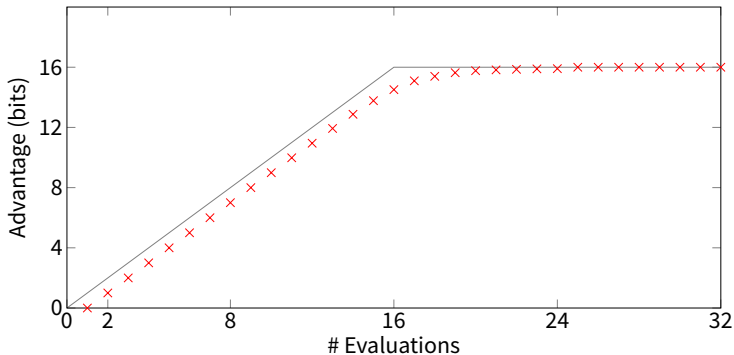
  - 14 additional permutation rounds for tag comparison
  - No noteworthy increase in code-size/area
  - No changes to Isap algorithm and cryptographic properties

Statistical (Ineffective) Fault Analysis (SFA/SIFA)

- Attack:
  - Query a keyed primitive using multiple different inputs and inject a fault in a certain location
  - Only collect those inputs where the fault did not affect the computation
  - Evaluate distributions of certain state bits using the collected inputs and partial key guesses
- ISAPRK limits amount of different queries to primitive with same key to 2

Accumulated Interference: Estimating $\mathrm{AG}_{\mathtt{sifa}}(\boldsymbol{X}, \boldsymbol{q}, r)$



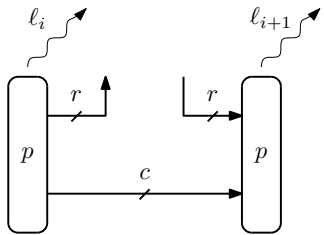
Evaluation Setup: Chipwhisperer-Lite with XMEGA128D4 target using clock glitches [DMP20]

Differential Fault Analysis

- Attack:
  - Query decryption with constant nonce
  - Inject faults at different locations before plaintext extraction
  - Use differences in plaintext (or leakage thereof) to recover the state
- In case of ISAP one only learns $K_E^\star$
- Adapted attack strategy for learning K exists [DMP20]
  - Combinations of precise faults in ISAPRK and ISAPENC during one execution
  - Quadratic amount of faulty executions

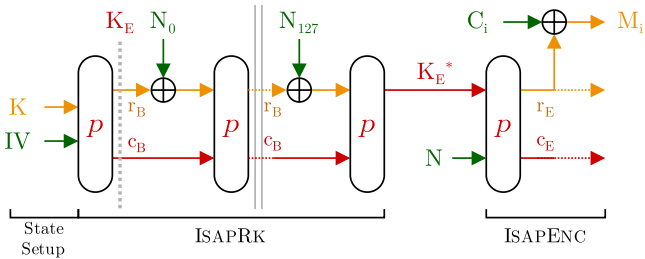
Profiling/Simple Power Analysis (SPA)

- ISAP's sponge-based mode gives SPA hardening
  - Leakage behaves similar to rate
  - Cryptographic properties ensure bounded security loss for bounded leakage
- Concrete application in [SP20]



Profiling/Simple Power Analysis (SPA)

- SPA leakage on 32-bit platform using HW acceleration for Ascon-*p* [SP20]
  - Green values are public (or leak fully)
  - Orange values create some leakage in 32-bit chunks
  - Red values result in hard to exploit leakage



Applications of ISAP Outside of LWC

- High performance AEAD in HW with protection/hardening against SCA/FI:

		MAC (0+x)				AEAD (x+0)			
Algorithm	Urol	Latency	64B	1 536B	long	Latency	64B	1 536B	long
ISAP-A-128A	1	217	5.1	1.9	1.8	378	8.5	3.0	2.8
ISAP-A-128A (StP)	1	230	5.1	1.9	1.8	392	8.5	3.0	2.8
ISAP-A-128A	2	116	2.8	1.0	1.0	199	4.6	1.8	1.6
ISAP-A-128A	4	66	1.6	0.7	0.6	109	2.7	1.1	1.1

Numbers represent cycles (for latency) or c/b (for throughput) of authentication decryption (x+0) or tag verification (0+x). Urol indicates the number of permutation rounds that are executed within one clock cycle.

Questions

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