Leakage and Tamper Resilient Permutation-Based Cryptography

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Motivation

- "Black box" model very popular in crypto
  - Attacker knows algorithm but only sees inputs/outputs
  - No information about secret key
  - Attacker cannot observe/influence the internal state
- Clear since 1990's that black boxes are a very optimistic assumption
  - Easy to mount side-channel attacks [Koc96; KJJ99]
  - Easy to mount fault attacks [BDL97; BS97]

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Motivation: Cost of Algorithmic Countermeasures

- Combined runtime/area overheads [BBC+20]:
  - Profiled Power Analysis: $1 - 5\times$
  - Differential Power Analysis: $5 - 100\times$
- Especially problematic for embedded devices:
  - Smart cards, root of trust silicon, ...
- Standardization effort by NIST: Lightweight Cryprography (LWC) [NIS18]
  - More performance than AES but same 128-bit security
  - Allow cheaper algorithmic countermeasures
  - Leakage resilience: Prevent physical attacks on mode-level

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Accumulated Interference

- Previous analysis of LR often in bounded leakage model
  - Adversary can choose any leakage function with bounded range [DP08]
  - Each new primitive call leaks $\leq \lambda$ bits $\rightarrow$ simplification!
  - Fault attacks are not considered
- This work:
  - More practical framework for evaluating leakage resilience
  - Closer fit to actual attacks (observable leakage)
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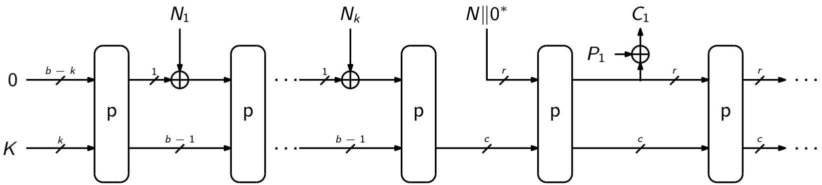
Accumulated Interference

- Accumulated gain (AG) represents leakage and tampering
- We bound leakage as the AG over time: $\mathrm{AG}(i)$
  - More accurate bounds on $\mathrm{AG}(i)$ derived through measurements
- Suited for permutation-based cryptography
  - Discussion example: Asakey
  - Direct implications for the NIST LWC finalist Isap [DEM+20]

Asakey: Nonce-based Stream Encryption

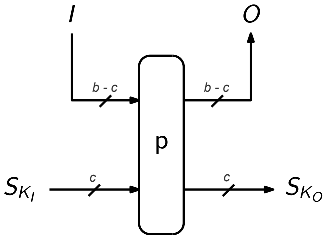


- Asakey ≈ encryption part of Isap [DEM+20]
- Nonce is absorbed bit by bit
  - Sponge-variant of GGM construction [GGM86]
  - Attacker observes at most 2 different inputs under same key

Accumulated Interference

$$\mathbf{Adv}^{\text{i-ai}}_{\textsc{Asakey}}(\mathsf{A}) \le \sum_{i=1}^{p} \left(\frac{1}{2^{k-\tau-\mathrm{AG}(i)}} + \frac{\nu^{Q-q}_{r-\tau,c-\tau} + 1}{2^{c-\tau-\mathrm{AG}(i)}} + \frac{Q + 2qk + 1}{2^{b-\tau-\mathrm{AG}(i)}} \right) + \frac{(Q+2qk)q + 2\nu^{Q-q}_{r-\tau,c-\tau}}{2^{c-\tau}} + \frac{\binom{Q+2qk+1}{2} + 2\binom{Q+qk+1+p}{2}}{2^{b-\tau}}$$

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
  - $\boldsymbol{q}$ evaluations of p per input
  - r maximal number of X_i with the same inner part

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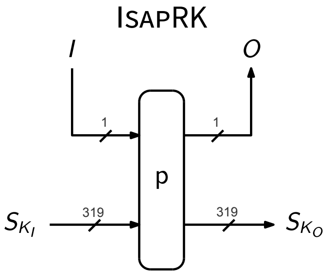

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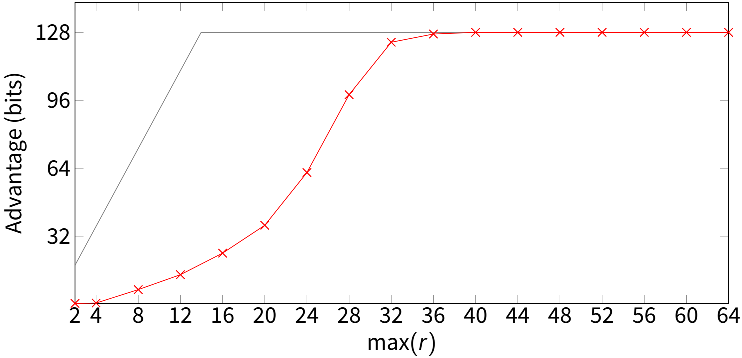
Accumulated Interference: Estimating $\mathrm{AG}_{\mathtt{DPA}}(\boldsymbol{X}, \boldsymbol{q}, r)$



Evaluation Setup: Chipwhisperer-Lite with XMEGA128D4 target

Implications for AsaKey

- Importance of construction is to bound r and $\max(\boldsymbol{q})$
- AsaKey only bounds $r = 2$
  - Helps against attacks like DPA, SFA, SIFA, …
- $\max(\boldsymbol{q})$ unbounded
  - DFA still possible
- In the paper: Strengthened AsaKey
  - Bounds $\max(\boldsymbol{q})$ to a small constant
  - Stateful scheme that steadily increases the nonce
  - Stores intermediate states during nonce absorption

Conclusion

- More realistic framework to model side-channel and fault attacks for LR crypto
- Introduced (strengthened) ASAKEY as a discussion example
- Discussion of attacks like DPA, DFA, SFA, SIFA, …
- Open: Better construction to bound $\max(\boldsymbol{q})$?

Questions

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