Improved Collision-Correlation Power Analysis on First Order Protected AES

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Outline

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Collision attack

- K. Schramm, T. J. Wollinger and C. Parr. *A New Class of Collision Attacks and Its Application to DES.* FSE 2003.

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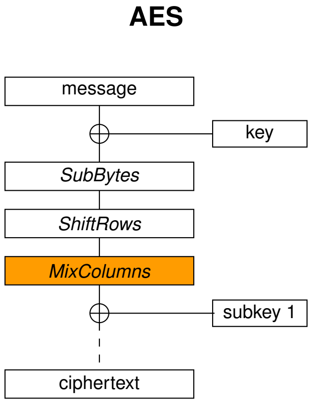

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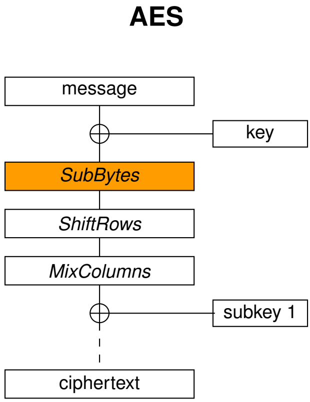

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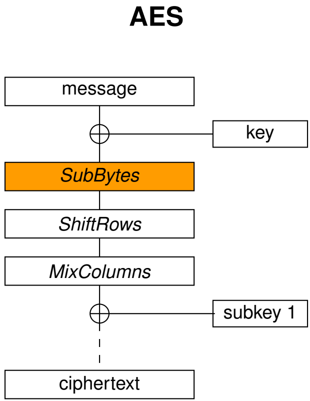
- A. Moradi, O. Mischke and T. Eisenbarth. *Correlation-Enhanced Power Analysis Collision Attack.* CHES 2010.
- . . .



Our Contribution

- Target first-order protected AES implementations
- Use correlation to detect internal collision
- Practical results on RISC 16-bit implementations
- Attacks validated using simulated and real curves
- Comparison with second-order techniques

Outline

Outline

AES Implementations

- We focus on AES-128 but our results can be applied to AES-192 and AES-256
  - message $M = (m_0\, m_1\, \dots\, m_{15})$
  - key $K = (k_0\, k_1\, \dots\, k_{15})$
  - ciphertext $C = (c_0\, c_1\, \dots\, c_{15})$
  - for $i \in [0, 15]$ we denote $x_i = m_i \oplus k_i$
- Attack on *SubBytes* function in first round
- Two protections against first-order attacks are considered:
  1. substitution table masking: $S'(x_i \oplus u) = S(x_i) \oplus v$
     same masks u and v for all bytes
  2. masked pseudo-inversion in $GF(2^8)$ using inversion in subfield $GF(2^4)$ (and $GF(2^2)$): $I'(x_i \oplus u_i) = I(x_i) \oplus u_i$
     16 different masks but same input and output masks

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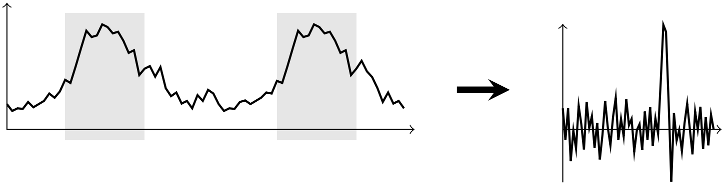
Principle

Attack Principle

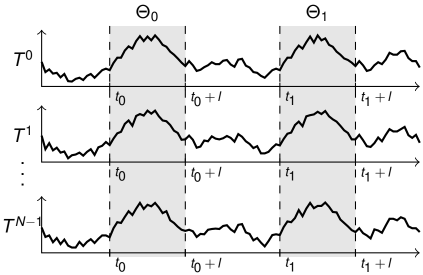
Detect internal collisions between data processed in blinded S-Boxes on the first AES round.

$data1 \oplus mask = data2 \oplus mask$



Collision-Correlation Analysis (1)

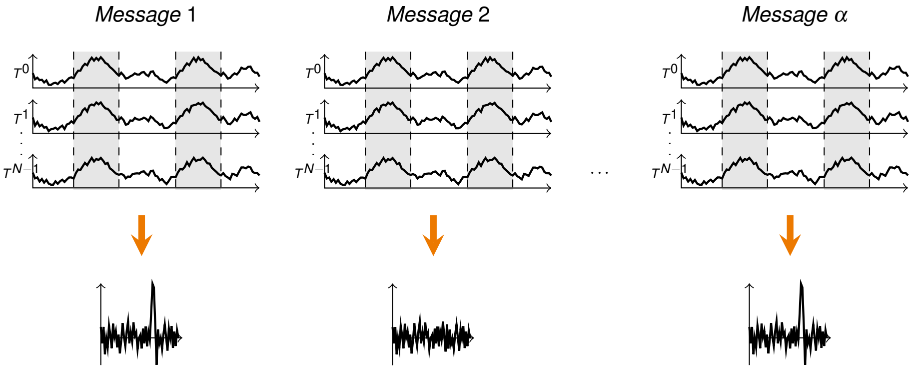
- Encrypt N times the same message M
- Collect the power traces T^n, $0 \leq n \leq N-1$
- Consider two instructions whose processing starts at times t_0 and t_1
  l points are acquired per instruction processing
- Construct the two series $\Theta_0 = (T^n_{t_0})_n$ and $\Theta_1 = (T^n_{t_1})_n$ of power consumptions segments



- Apply a statistical treatment to (Θ_0, Θ_1) to identify if same data was involved in $T^n_{t_0}$ and $T^n_{t_1}$
- We choose the Pearson correlation factor $\hat{\rho}_{\Theta_0,\Theta_1}(t) = \dfrac{\mathrm{Cov}(\Theta_0(t), \Theta_1(t))}{\sigma_{\Theta_0(t)}\sigma_{\Theta_1(t)}}$

Collision-Correlation Analysis (2)

Repeat with other messages until having enough information on key bytes



Outline

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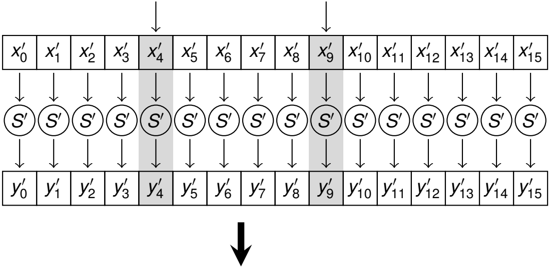
First Attack Description (1)

Principle = detect when two `SubBytes` inputs (and outputs) are equal in first AES round

$$m_4 \oplus k_4 \oplus u \quad = \quad m_9 \oplus k_9 \oplus u$$



$$k_4 \oplus k_9 \quad = \quad m_4 \oplus m_9$$

Result = provide a relation between two key bytes

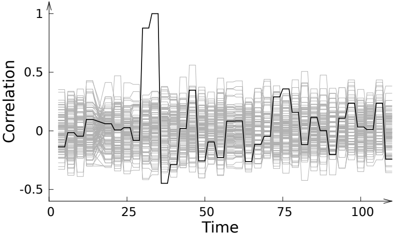
First Attack Description (2)

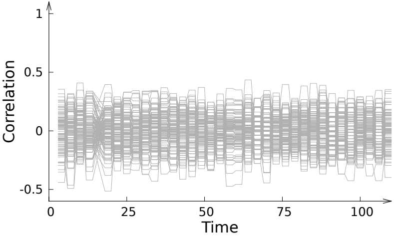
- Repeat for several random messages M until enough relations have been found
  - Encrypt N times the same message M and collect the N traces of first AES round
  - Construct the 16 series Θ_i corresponding to the computation of $S'(x_i \oplus u)$
  - For the 120 possible pairs (i_1, i_2) compute $\hat{\rho}_{\Theta_{i_1}, \Theta_{i_2}}(t)$
  - When a correlation peak appears a relation between k_{i_1} and k_{i_2} has been found

$\Rightarrow$ On average 59 messages are needed
Total number of curves $= 59 \times N$

Results on simulated curves

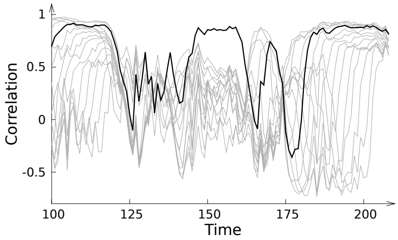
Correlation traces obtained on simulated curves for $N = 16$





Results on real curves

Correlation traces obtained on real curves for $N = 25$



Total number of acquisitions : $25 \times 59 \approx 1500$

First Attack Improvement

Remark: only collision events are exploited but they are not so frequent

Idea: exploit non-collision events as they are numerous

- For a given message only 0, 1 or 2 collisions most of the time among 120
- All other pairs (i_1, i_2) reveal impossible values for $k_{i_1} \oplus k_{i_2}$
  $\Rightarrow$ they are added to a blacklist
- Choose a message which have the maximum probability to generate a collision
- The penalty of a candidate message corresponds to the number of pairs (i_1, i_2) for which $m_{i_1} \oplus m_{i_2}$ is already blacklisted

$\Rightarrow$ On average 27.5 messages are needed
Total number of curves $= 27.5 \times N$

On previous exemple we need $27.5 \times 25 \approx 700$ instead of 1500 curves.

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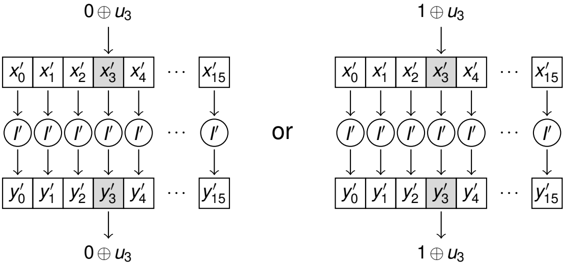
Second Attack Description (1)

Previous attack cannot be applied to masked inversion as masks are different per bytes.



Collision between input and output reveals one key byte except one bit:

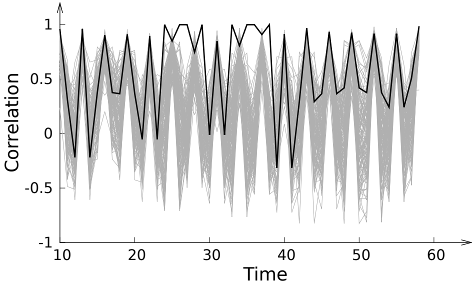
$$k_i = m_i \qquad \text{or} \qquad k_i = m_i \oplus 1$$

Second Attack Description (2)

- For each guess $g \in [0, 127]$
  - Encrypt N times message M s.t. $m_0 = g$ and collect traces $T^{n,g}$, $0 \leq n \leq N-1$
  - Construct series:
    Θ_0^g corresponding to the load of $x_0 \oplus u_0$ before inversion
    Θ_1^g corresponding to the store of $I(x_0) \oplus u_0$ after inversion
  - Compute $\hat{\rho}_{\Theta_0^g, \Theta_1^g}(t)$
- The highest correlation peak reveals k_0 except 1 bit

Practical Results

Correlation traces obtained on simulated curves for the pseudo-inversion of the first byte in $GF(2^8)$ with $N = 16$



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Definitions

Target first implementation i.e. S-Box masking.

Consider three functions commonly used for second-order attacks:

- $f_1(x,y) = |x - y|$
- $f_2(x,y) = |x - y|^2$
- $f_3(x,y) = |x \times y|$

Use as distinguisher the Pearson correlation factor $\hat{\rho}$

Second Order Attack Modeling

- Construct the series of power consumptions of two S-Box outputs for N messages

$$\theta_0 = (HW_n(S(x_{i_1} \oplus u) \oplus v) + \omega_\sigma)_{0 \le n \le N-1}$$

$$\theta_1 = (HW_n(S(x_{i_2} \oplus u) \oplus v) + \omega_\sigma)_{0 \le n \le N-1}$$

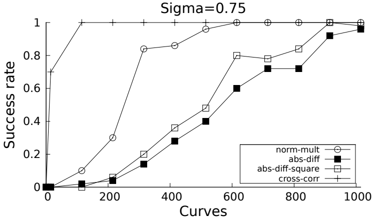
- Compute the series of estimated values of S-Box outputs for key guesses g_{i_1} and g_{i_2}

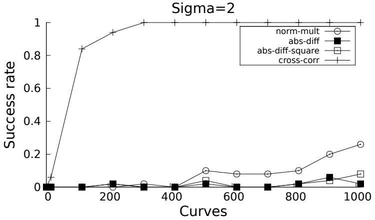
$$W_{g_{i_1}, g_{i_2}} = (HW_n(S(m_{i_1} \oplus g_{i_1}) \oplus S(m_{i_2} \oplus g_{i_2})))_{0 \le n \le N-1}$$

- The right key byte is obtained for the highest correlation value $\hat{\rho}(f_i(\theta_0, \theta_1), W_{g_{i_1}, g_{i_2}})$

Comparison

Compare the success rate of second-order power analysis methods with the collision-correlation one by simulating these attacks for different standard deviation σ of noise ω.





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Conclusion

- Improved collision-correlation technique defeats some first-order protected implementations
- Need less than 1500 acquisitions
- More powerful than previous second-order power analyses
- No need to establish a consumption model for correlation

Thanks for your attention.