Robust Codes for Fault Attack Resistant Cryptographic Hardware*

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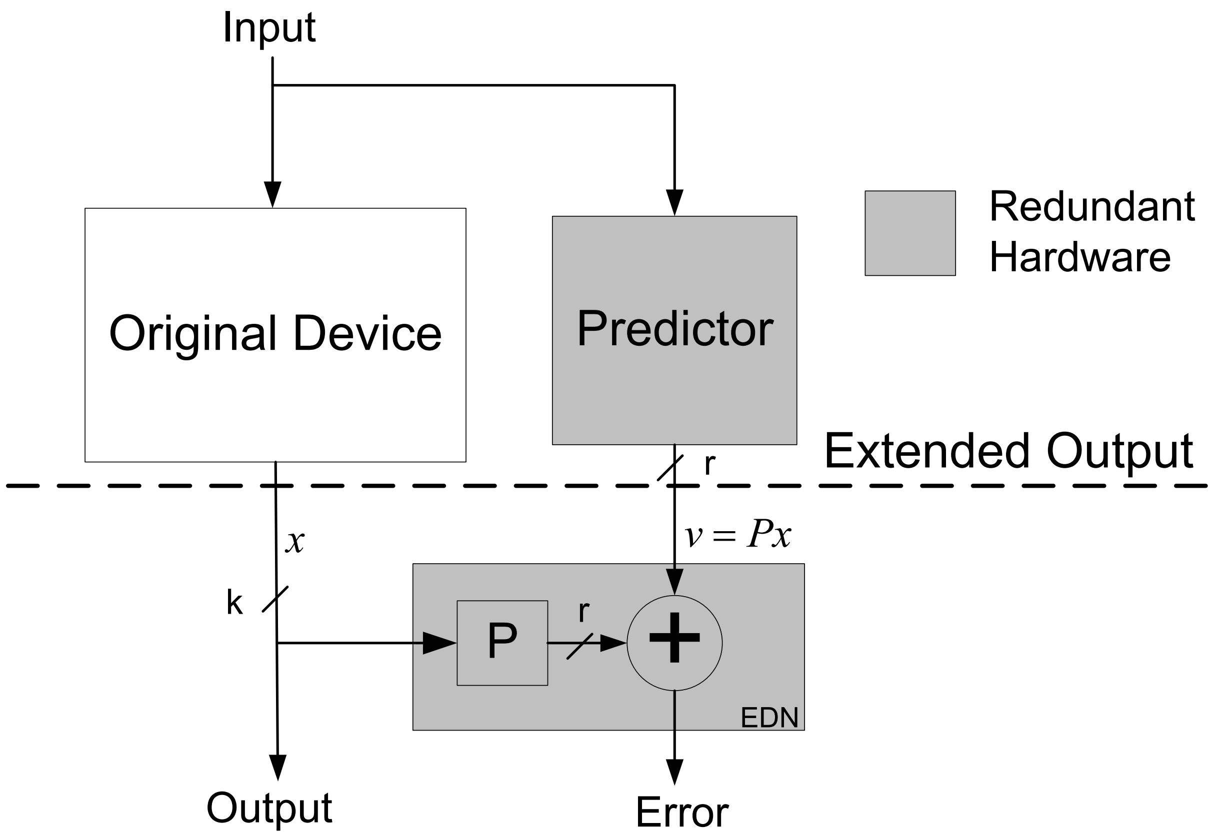
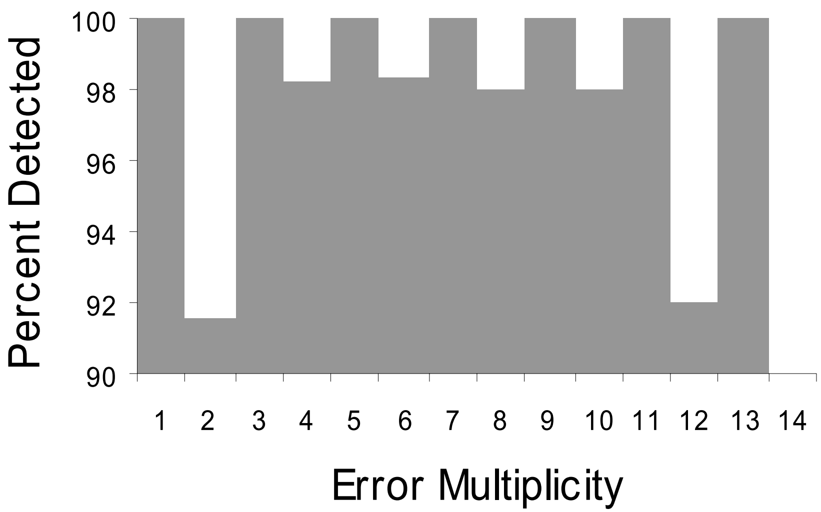
Concurrent Error Detection



Linear Code Limitations

- Detection depends on error multiplicity and error distributions. Cannot be predicted for an attack.
- Large differences in probabilities of detection for different classes of errors:



Linear Duplication (k=r=7)

Robust Code

Probability of Missing an error *e*

$$Q(e) = \frac{|\{w \mid w \in C, w \oplus e \in C\}|}{|C|} = \text{Constant}, \quad e \neq 0$$

Robust Code Construction

$$C_V = \{(x, v) \mid x \in GF(2^k), v = (Px)^{-1} \in GF(2^r)\}$$

Error Masking Condition

$$(P(x \oplus e_x))^{-1} = (Px)^{-1} \oplus e_v$$

Robust Codes (inversion based)

	Number of errors		
Prob. of detection	Linear	Robust (r is odd)	Robust (r is even)
0	2^k	2^{k-r}	2^{k-r}
1	$2^n - 2^k$	$2^{n-1} + 2^{k-1} - 2^{k-r}$	$2^{n-1} + 2^{k-1} - 2^{k-r} + 2^k - 2^{k-r}$
$1-2^{-r+1}$	0	$2^{n-1} - 2^{k-1}$	$2^{n-1} - 2^{k-1} - 2(2^k - 2^{k-r})$
$1-2^{-r+2}$	0	0	$2^k - 2^{k-r}$

Robust Codes

If $||e||=1$

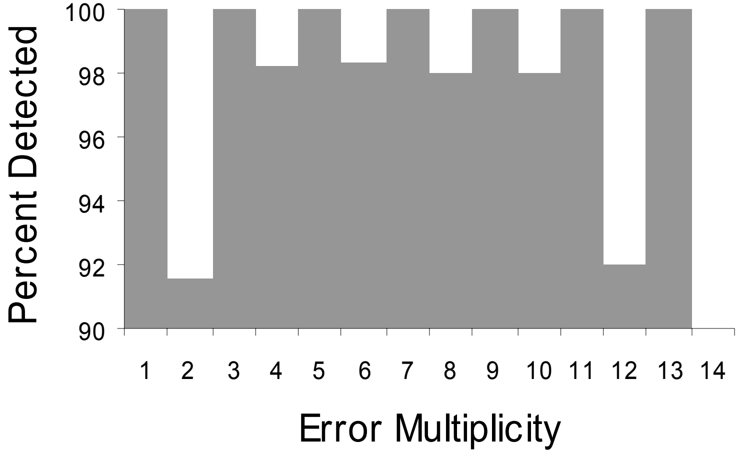
$$\max Q(e) = 0 \qquad \textit{for linear and Robust}$$

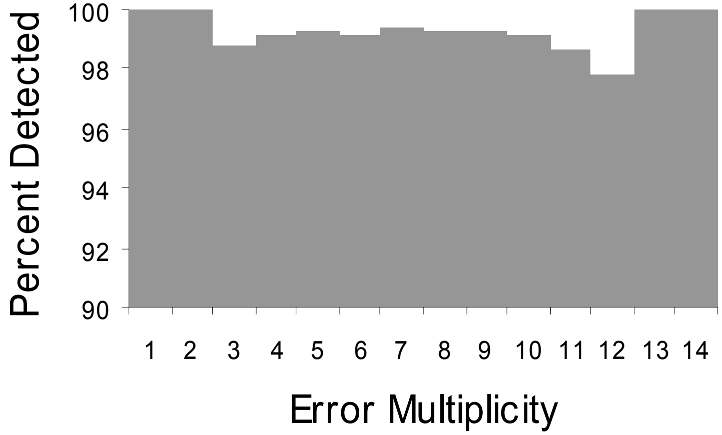
If $||e||=1$

$$\max Q(e) = \{0,1\} \qquad \textit{for linear}$$

$$\max Q(e) = \{0, 2^{-k+1}, 2^{-k+2}\} \qquad \textit{for Robust}$$

Robust Detection

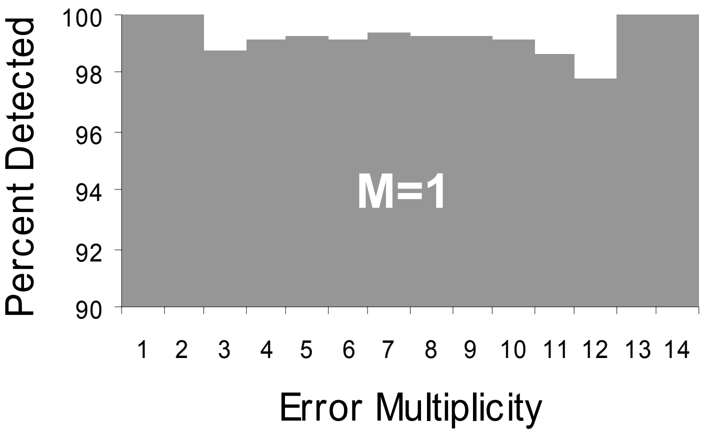


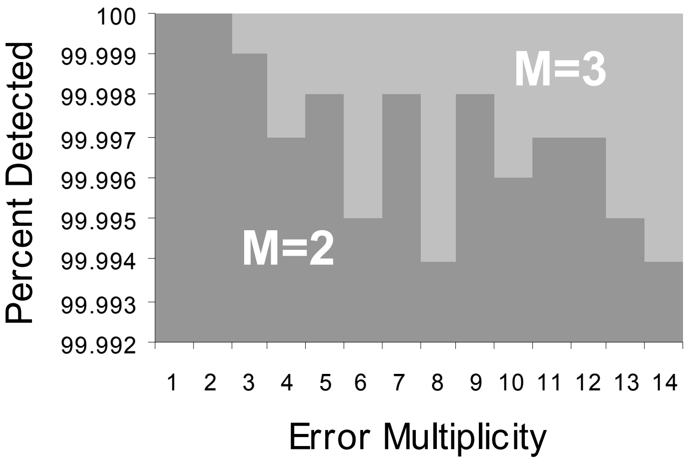


$$V = \{(x,x) \mid x \in GF(2^k)\}$$

$$C_V = \{(x,v) \mid x, v \in GF(2^k), v = (x)^{-1}\}$$

Robust Detection, Data Dependence





Maximum probability of missing a repeating error after *M* messages (k=r)

$$\max Q(e) = 2^{-r+1}, M = 1$$

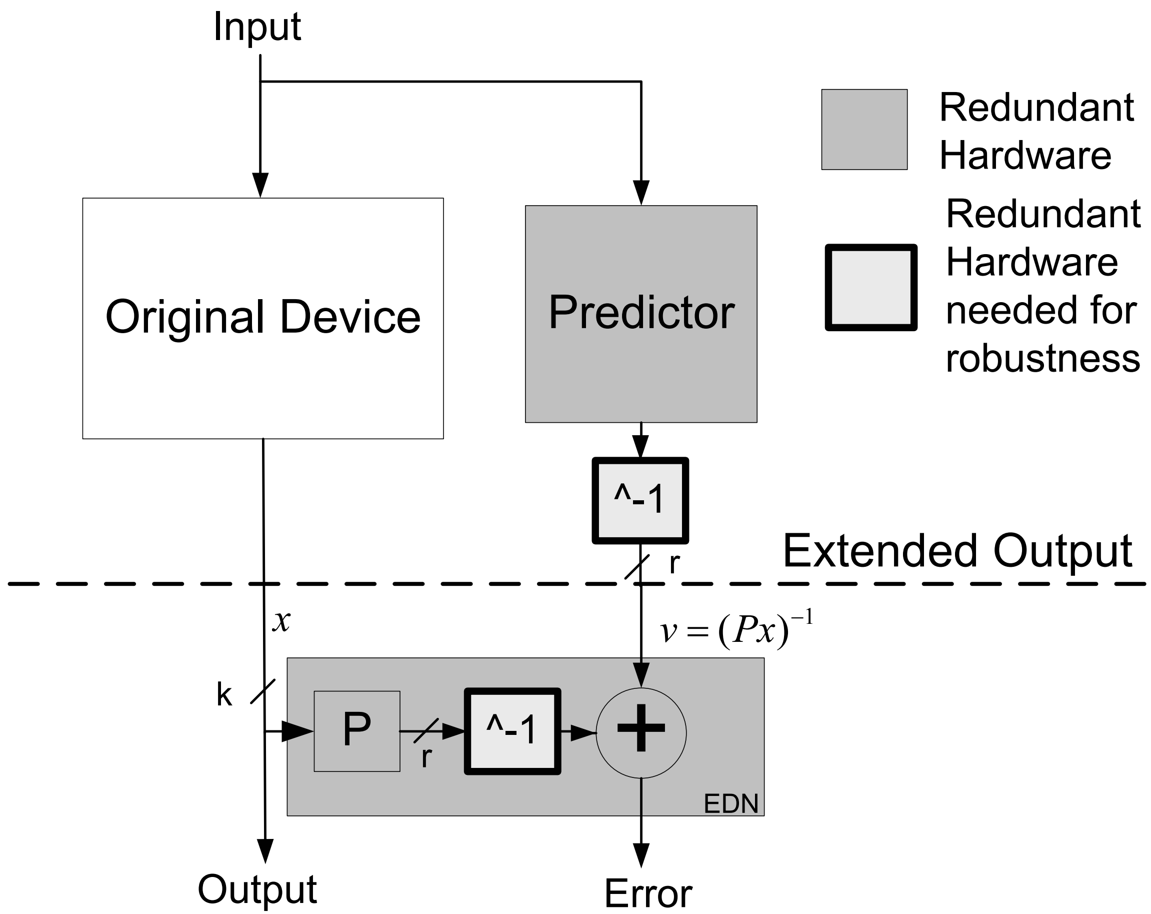
$$\max Q(e) = 2^{-r}, M = 2$$

$$\max Q(e) = 0, M = 3$$

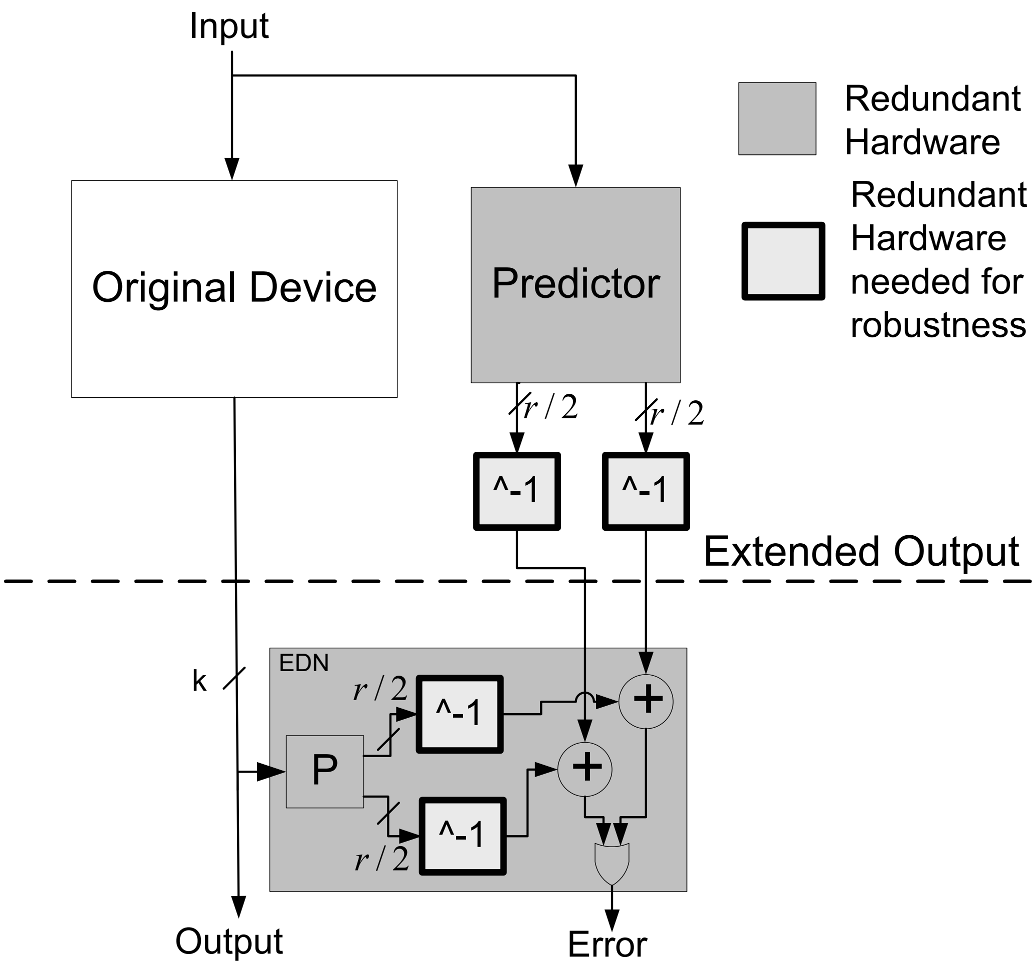
Robust Codes

- With Robust protection it is difficult to inject errors in a encryption device (DFA attacks) which are not detected since error detection depends not only on the errors (as it does for linear codes), but also on the message (output of the device) which depends on the secret key.

Application to Hardware



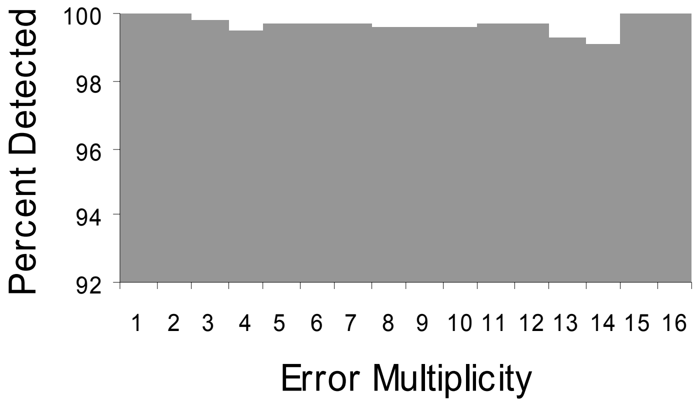
Overhear Reduction



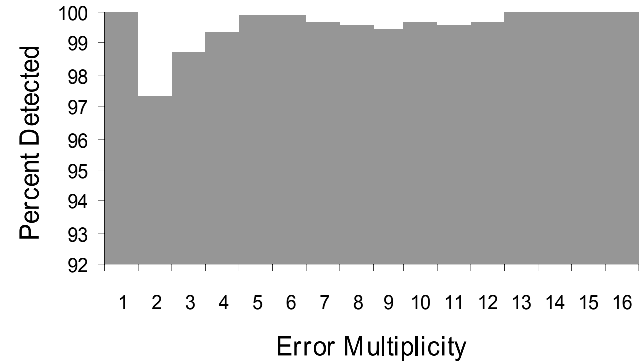
Division of one large inversion into *t* smaller inversions

Signature Splitting and Detection

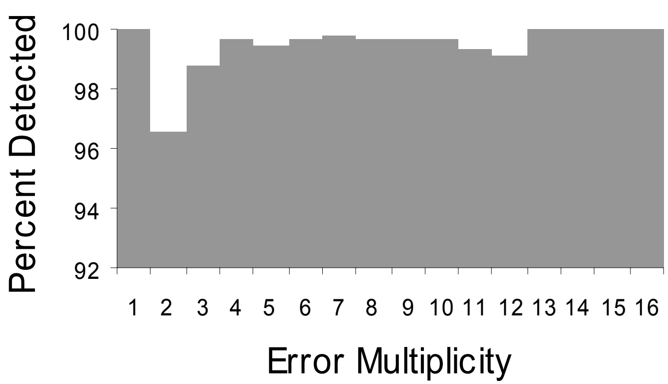
t=1 (robust)



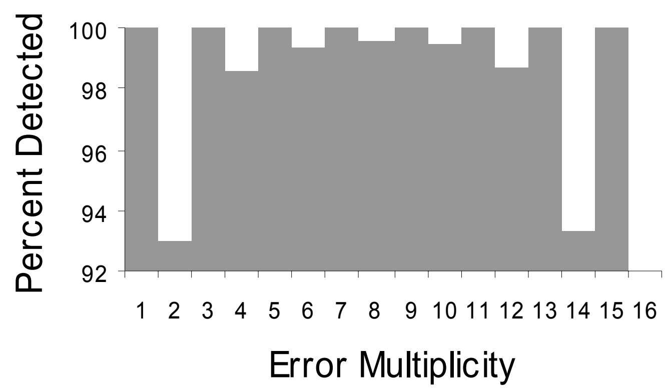
t=2



t=4



t=8 (linear)



Reduction of Overhead

Architecture	Overhead
t=1 (linear)	50%
t=4 (robust)	53%
t=8 (robust)	58%
t=16 (robust)	72%
t=32 (robust)	80%

Reduction of hardware overhead for a FPGA implementation of AES-128 with where k=128 r=32.

Splitting of signatures allows for a robustness/hardware tradeoff

References

- Mark Karpovsky and Alexander Taubin, "A New Class of Nonlinear Systematic Error Detecting Codes", IEEE Trans Info Theory, Vol 50, No.8, 2004, pp.1818-1820
- Mark Karpovsky, Konrad J. Kulikowski, and Alexander Taubin, "Robust Protection Against Fault-Injection Attacks of Smart Cards Implementing the Advanced Encryption Standard". T Proc. Int. Conference on Dependable Systems and Networks (DSN 2004), July, 2004
- Mark Karpovsky, Konrad J. Kulikowski, and Alexander Taubin, "Differential Fault Analysis Attack Resistant Architectures for the Advanced Encryption Standard" . Proc. World Computing Congress, Cardis, Aug., 2004

Conclusions

- The protection provided by linear error detecting codes is not uniform and is not suitable for cryptographic hardware which is susceptible to fault attacks
- We presented a method of protection based on nonlinear systematic robust codes which can provide for uniform protection against all errors thus drastically reducing the probability that an attacker will be able to inject an undetected error.
- We also presented an optimization which allows for a tradeoff between the level of robustness and area overhead.