Message-aimed Side Channel and Fault Attacks against Public Key Cryptosystems with homomorphic Properties

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Introduction

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- which require
  - the PKC to have a homomorphic property: $\mathcal{E}(a) \bullet \mathcal{E}(b) = \mathcal{E}(a \odot b)$
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- which aim at recovering the message to certain ciphertext
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- We will consider the RSA and McEliece cyptosystems
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  - *compare the results for both PKCs*

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Manger's Attack

- RSA-OAEP Encoding introduced to thwart Bleichenbacher's Attack against RSA with PKCS#1 v1.5 Encoding
- The OAEP is a so called CCA2 conversion that secures a cryptosystem against adaptive chosen ciphertext attacks
- (any manipulation of an original ciphertext is detected during the decryption)
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RSA

- public key: public exponent e and public modulus n
- private key: private exponent d with $x^{ed} = x \bmod n$
- encryption: $z = m^e \bmod n$
- decryption: $m = z^d = m^{ed} \bmod n$

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OAEP Encoding

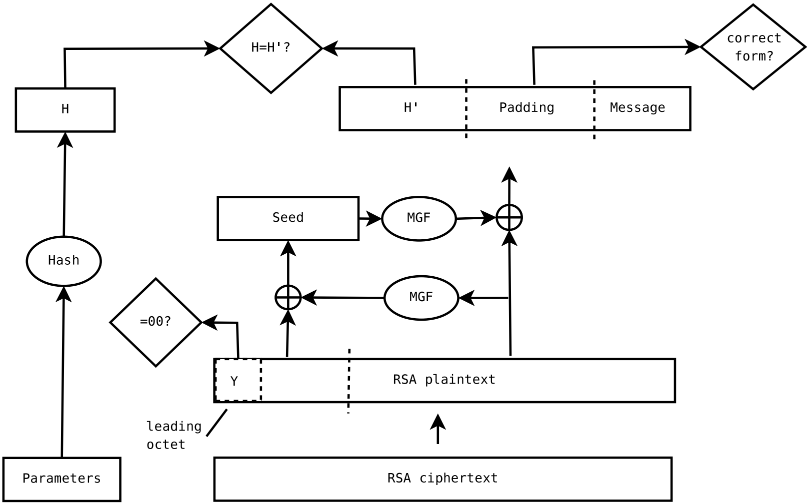
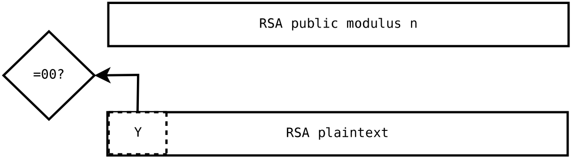


Figure: The RSA-OAEP decoding procedure. Here, $\oplus$ denotes XOR.

Manger's Attack - the observable Error Condition



- OAEP Decoding checks that $Y = 0$
- ($Y \neq 0 \rightarrow$ "supernumerary octet")
- $Y \neq 0$ can be learned either through
  - a specific error message
  - shorter time to the error message compared to later OAEP errors

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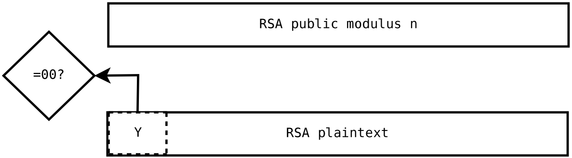

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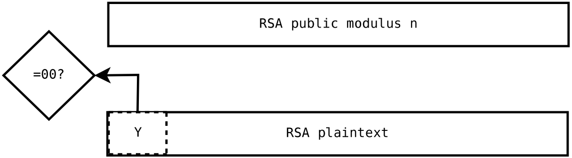

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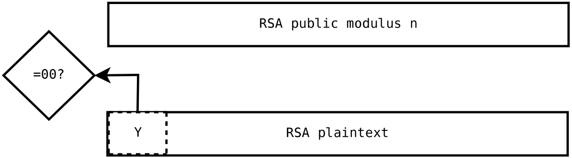

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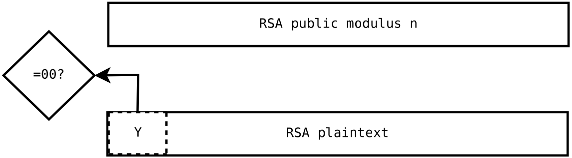

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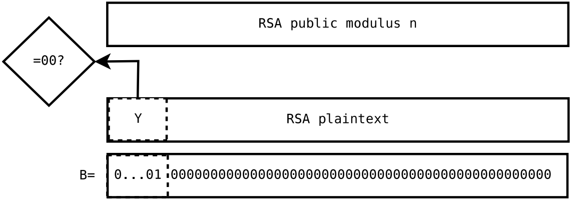

- The attacker wants to decrypt the ciphertext $c_0 = m_0^e \bmod n$
- He chooses $f \in \{0, 1, \ldots, n-1\}$
- He creates ciphertexts $c_f = f^e c_0 = (fm_0)^e \bmod n$
- He observes the decryption of c_f
- If $Y \neq 0$ he learns $\boxed{fm_0 \bmod n \geq B}$
- Manger gives a specific strategy how to choose f initially
- and how to adapt f in in subsequent queries

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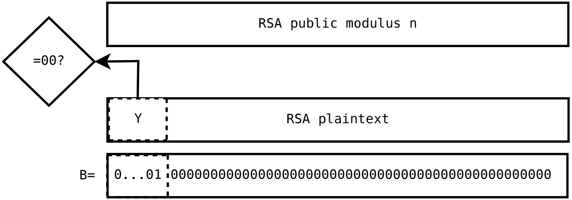

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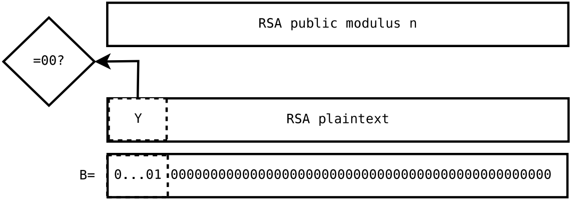

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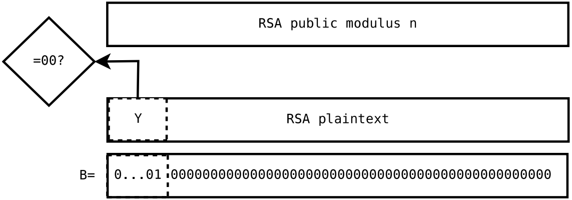

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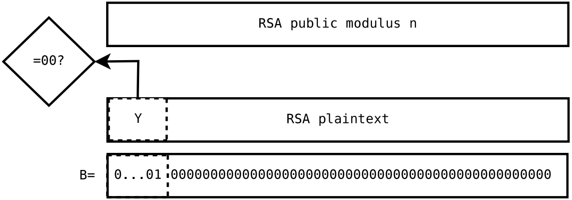

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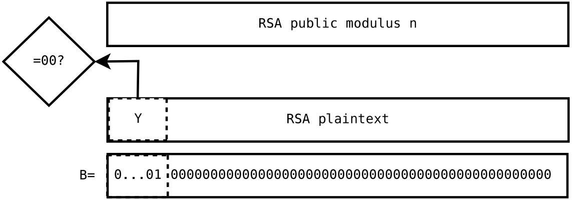

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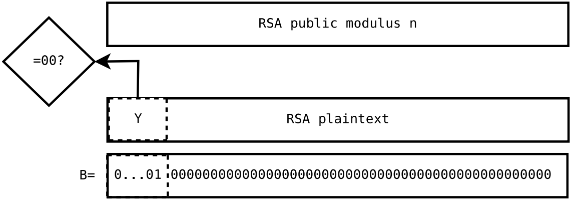

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Recent Work: a potential Vulnerability in the Integer to Octet String Conversion

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void BigInt::binary_encode(byte output[]) const
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  const u32bit sig_bytes = bytes();
  for(u32bit j = 0; j != sig_bytes; ++j)
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- the running time of this routine obviously depends on the number of octets of the encoded integer
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- independent of encoding method

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- it was also shown that in special cases there are potential vulnerabilities already in the last multiprecision integer (MPI) routine dealing with the message representative
- based on
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  - Encoding in a linear ECC = Matrix multiplication (over $\mathbb{F}_2$):
    - $\vec{c} = \vec{v}G$
    - G is called a generator matrix of the code
    - code word $\vec{c}$ is longer than message word $\vec{v}$
  - Decoding in a linear ECC = code specific decoding algorithm
    - decodes $\vec{c}' = \vec{c} \oplus \vec{e}$ with $\mathrm{wt}(\vec{e}) \leq t$ back to $\vec{v}$
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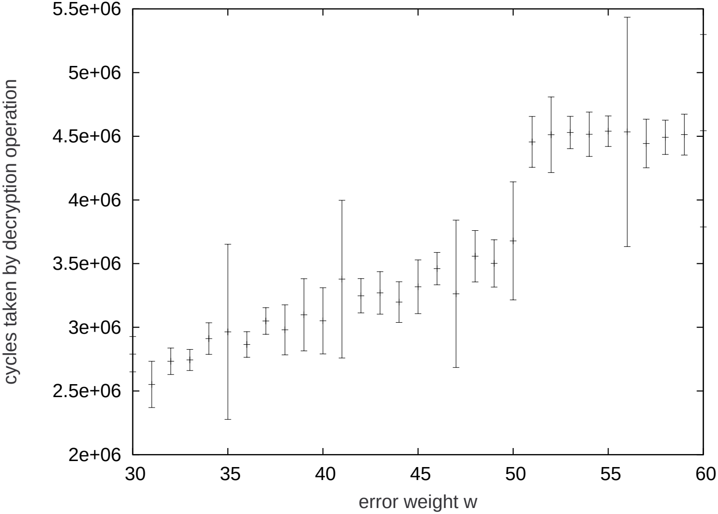
Timing Effects in the McEliece Decryption for $t = 50$



Exploitation of the Timing Effects

- An attacker wishes to decrypt a certain ciphertext $\vec{z}$
- he creates manipulated versions of this ciphertext:
  - in each he flips a different bit
  - and thus carries now $t-1$ or $t+1$ errors
- he observes the decryption and (through timing) tries to determine whether
  - $\mathrm{wt}(\vec{e}) = t-1 \rightarrow$ the flipped bit was an error position
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A new Vulnerability in the Root Finding Algorithm

- During the McEliece decryption the Error Locator Polynomial (ELP) plays a key role
  - it is computed
  - its roots (zeros) are determined
- Previous works on timing attacks took only into account the effect of the degree of the ELP on the running time ($\rightarrow$ linear incline for $\mathrm{wt}(\vec{e}) \leq t$)
- But an efficient root finding algorithm can introduce a new vulnerability:
  - to speed up the time consuming root finding $\rightarrow$ factoring of the ELP
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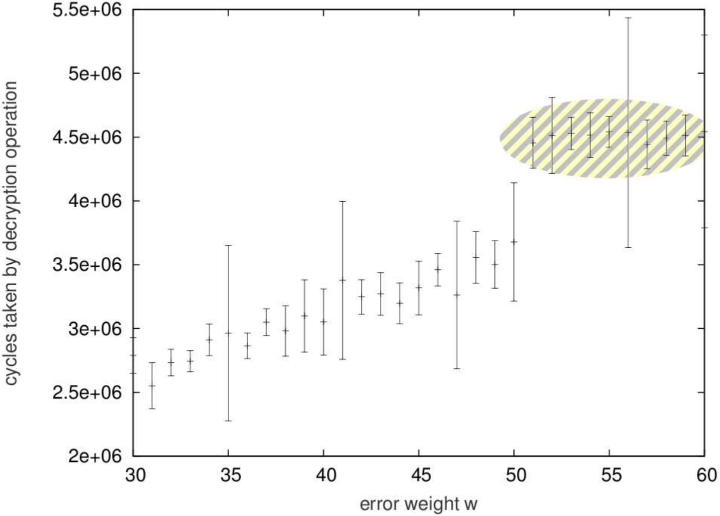
Timing Effects from the Factoring inside the Root Finding Algorithm



Comparison of the McEliece and RSA cryptosystems

	RSA	McEliece
homom. Property	$\mathcal{E}(a) \cdot \mathcal{E}(b) \equiv \mathcal{E}(a \cdot b) \bmod n$	$\mathcal{E}(a) \oplus \mathcal{E}(b) = \mathcal{E}(a \oplus b)$
observ. Prop.	(lead. octet = 0?) # octets in m	$\mathrm{wt}(\vec{e})$

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Message Encoding	Encoding in $\mathbb{Z}_n$	Encoding in $\mathbb{F}_2^n$
CCA2 Check	OAEP Check	appropriate CCA2 Check

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- Ideal Countermeasures would already ensure the *observable plaintext property* to be unambigous during the basic decryption
- then the subsequent operations (encoding of the message representative and the CCA2-conversion) would be relieved from countermeasures
- In McEliece the number of errors can be forced to be t during decryption
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  - (RSA: number of leading zero octets
  - McEliece: number of "errors" in ciphertext)

  must not be revealed through timing
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  - certain algorithm part must have timing irrespective of that plaintext property (e.g. encoding of $\mathbb{Z}_n$ elements)
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