NTNU | Norwegian University of Science and Technology

PADDING ORACLES

TTM4205 – Lecture 13

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19.10.2023

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Reference Material

These slides are based on:

- The referred papers in the slides
- JPA: parts of chapter 10
- DW: parts of chapter 6

Padding Oracles

By this we mean, on a high level, an API that allows an adversary to check if some input is correctly formed.

We limit ourselves to input with a particular padding.

A limited version of the protocol APIs from last week.

Padding Oracles

We will look at symmetric and asymmetric padding schemes:

- more in depth on CBC mode (last time)
- extension attacks against hashing (last time)
- padding attacks against RSA scheme (today)

Several of which are relevant to the weekly problems.

We will also look at some mitigations to these issues.

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Textbook RSA

The plain RSA encryption scheme works as follows:

KGen:

- Samples primes p and q of appropriate size and entropy
- Use fixed e and compute $d \equiv e^{-1} \bmod \operatorname{lcm}(p-1, q-1)$
- Output the key pair $\mathsf{pk} = (e, n = p \cdot q)$ and $\mathsf{sk} = (d, p, q)$

Textbook RSA

The plain RSA encryption scheme works as follows:

Enc:

- Takes as input a message m and public key $\mathsf{pk} = (e, n)$
- Computes the ciphertext $c \equiv m^e \bmod n$ and outputs c

Textbook RSA

The plain RSA encryption scheme works as follows:

Dec:

- Takes as input a ciphertext c and secret key $\mathsf{sk} = (d, p, q)$
- Computes the message $m \equiv c^d \bmod p \cdot q$ and outputs m

Textbook RSA

Question: Why is not the textbook RSA scheme secure?

Textbook RSA

The following things make the RSA scheme insecure:

- It is not randomized and hence not even CPA secure
- Given a ciphertext you can search for the message
- High-entropy messages still gives the same ciphertext
- The Jacobi symbol of m and c will be the same

Solution: structured, but randomized padding

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RSA-PKCS#1v1.5

Let n be of k bytes. Given a message m of $\ell \leq k - 11$ bytes, the padded messages $\bar{m}$ of length k bytes is constructed as follows: $00\ 02$ $\{$at least 8 non-zero random bytes$\}$ 00 $\{m\}$.

Quite simple, not proven secure, not secure in practice...

Matthew Green in attacks, tokens/HSMs June 21, 2012 2,313 Words

A bad couple of years for the cryptographic token industry

SafeNet eToken PRO Anywhere

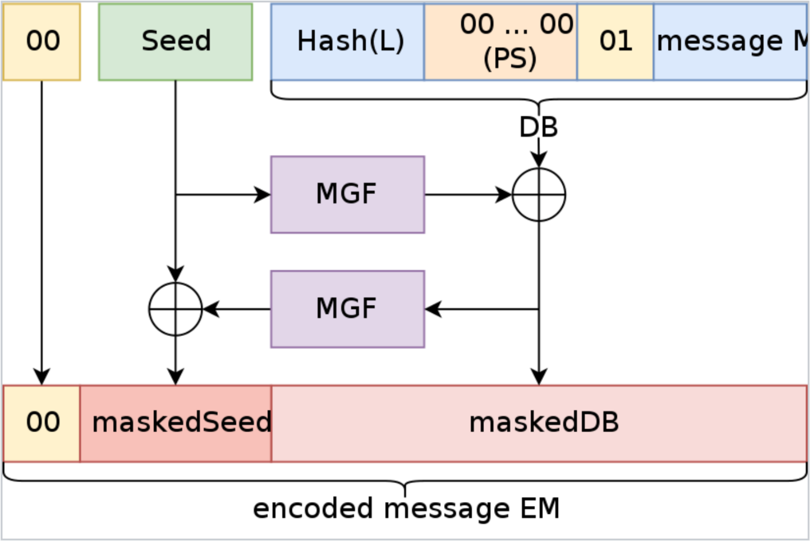
Figure: https://blog.cryptographyengineering.com/2012/06/21/bad-couple-of-years-for-cryptographic

OAEP

More complex, proven secure, what you should use:

- Let n be of k bytes and message m be of ℓ bytes.
- Let MGF and Hash be hash functions with output h bytes.
- Let L be a label (which can be set to the all zero string)
- Let seed be an ephemeral random string of h bytes.
- Let PS be a all zero string of length $k - \ell - 2h - 2$ bytes.

OAEP



00
Seed
Hash(L)
00 ... 00
(PS)
01
message M
DB
MGF
MGF
00
maskedSeed
maskedDB
encoded message EM

Optimal Asymmetric Encryption — How to Encrypt with RSA

Mihir Bellare*   Phillip Rogaway†

November 19, 1995

Figure: https://cseweb.ucsd.edu/~mihir/papers/oaep.pdf

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New cryptographers
Experienced cryptographers

The Bleichenbacher Attack

However, many implementations (still) use RSA-PKCS#1v1.5 or similar padding schemes (note that this is version 1.5).

Recall: $00\ 02$ $\{$at least 8 non-zero random bytes$\}$ 00 $\{m\}$.

Question: Assuming no integrity check of RSA ciphertexts, how could you attack this scheme?

The Bleichenbacher Attack

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- We know that if valid then $2 \cdot 2^{8(k-2)} \leq \bar{m} \cdot r < 3 \cdot 2^{8(k-2)}$.
- Repeat for fresh values r until we have a unique $\bar{m}$ left.

Oracle	Original algorithm	
	Mean	Median
FFF	-	-
FFT	215 982	163 183
FTT	159 334	111 984
TFT	39 536	24 926
TTT	38 625	22 641

Figure: https://eprint.iacr.org/2012/417.pdf

Chosen Ciphertext Attacks Against Protocols Based on the RSA Encryption Standard PKCS #1

Daniel Bleichenbacher

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Figure: https://spar.isi.jhu.edu/~mgreen/bleichenbacher.pdf

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Improving the Attack

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2. Trim the randomness to a specific interval $[a, b]$
3. Parallelization and threading and pre-computation
4. Adapt based on how strict padding checks are

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3. FTT: same as above, but also allows 0s in the "non-zero random bytes".

4. TFT: same as above, but 'ok' even if there are no zeros after the first byte.

5. TTT: padding is 'ok' as long as it starts with $0x$ 00 02.

Oracle	Original algorithm		Modified algorithm			
	Mean	Median	Mean	Median	Trimmers	Mean skipped
FFF	-	-	18 040 221	12 525 835	50 000	7 321
FFT	215 982	163 183	49 001	14 501	1 500	65 944
FTT	159 334	111 984	39 649	11 276	2 000	61 552
TFT	39 536	24 926	10 295	4 014	600	20 192
TTT	38 625	22 641	9 374	3 768	500	18 467

Table 1: Performance of the original and modified algorithms.

Figure: https://eprint.iacr.org/2012/417.pdf

Efficient Padding Oracle Attacks on Cryptographic Hardware*

Romain Bardou[1], Riccardo Focardi[2]**, Yusuke Kawamoto[3]***,
Lorenzo Simionato[2]†, Graham Steel[4]***, and Joe-Kai Tsay[5]***

[1] INRIA SecSI, LSV, CNRS & ENS-Cachan, France
[2] DAIS, Università Ca' Foscari, Venezia, Italy
[3] School of Computer Science, University of Birmingham, UK
[4] INRIA Project ProSecCo, Paris, France
[5] Department of Telematics, NTNU, Norway

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Protection

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- Use OAEP padding for encryption

Protection

- Use OAEP padding for encryption
- Encrypt-then-Authenticate

Protection

- Use OAEP padding for encryption
- Encrypt-then-Authenticate
- Do not use RSA for encryption

Questions?