NTNU | Norwegian University of Science and Technology

PADDING ORACLES: CBC AND SHA

TTM4205 – Lecture 11

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Reference Material

These slides are based on:

- The referred papers in the slides
- JPA: parts of chapter 4, 6 and 7
- DW: parts of chapter 2 to 4

Padding Oracles

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

We limit ourselves to inputs with a particular padding.

Padding Oracles

We will look at symmetric and asymmetric padding schemes:

- in depth on the CBC block cipher mode (today)
- extension attack against hashing (today)
- padding attacks against the RSA scheme (next)

Several of which are relevant to the weekly problems.

We will also look at some mitigations to these issues.

Contents

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- A variety of padding oracle attacks and patches in practice

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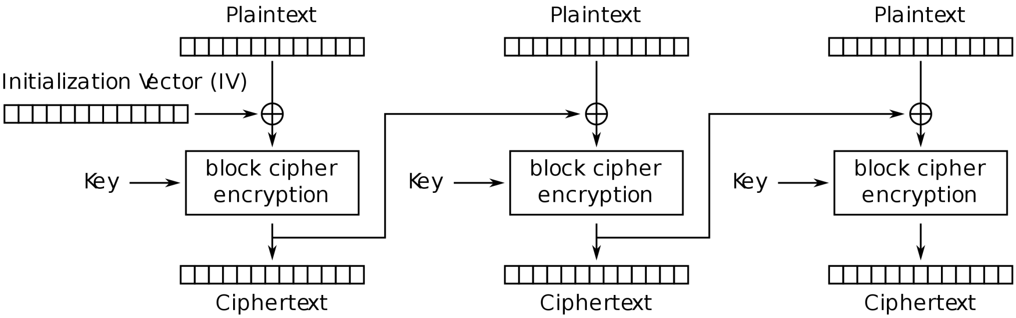
- Proposed in 1976, proven CPA-secure in 1997, broken 2002
- Secure against Chosen Plaintext Attacks (CPA, theory)
- Not secure against Chosen Ciphertext Attacks (CCA, practice)
- A variety of padding oracle attacks and patches in practice
- Revoked from some applications (e.g. TLS) in 2018

AES-CBC



Cipher Block Chaining (CBC) mode encryption

CBC Attack

- Each block must be of exactly 128 bits
- Shorter message leads to padding at the end
- Add one byte ends with 01, two with 02, etc. ...
- An API outputs errors when wrong padding

Question: What might an attacker do in this setting?

CBC Attack

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- Find next byte by $C_1[15] = X[15] \oplus 02$ and vary $C_1[14]$

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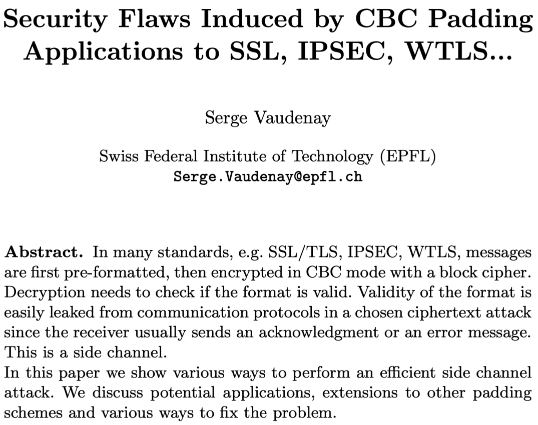
CBC Attack

- Let C_2 be an encryption of X that you want to decrypt
- Choose random C_1 and ask for $C_1|C_2$ to be decrypted
- Successful decryption if $C_1 \oplus X$ has valid padding
- Vary last byte of C_1 until correct to find last byte of X
- Find next byte by $C_1[15] = X[15] \oplus 02$ and vary $C_1[14]$
- Continue until you have all bytes of X, max $128 \cdot 16$ trials
- Continue until you have the whole message, block by block

CBC Attack



Security Flaws Induced by CBC Padding Applications to SSL, IPSEC, WTLS...

Serge Vaudenay

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Abstract. In many standards, e.g. SSL/TLS, IPSEC, WTLS, messages are first pre-formatted, then encrypted in CBC mode with a block cipher. Decryption needs to check if the format is valid. Validity of the format is easily leaked from communication protocols in a chosen ciphertext attack since the receiver usually sends an acknowledgment or an error message. This is a side channel.
In this paper we show various ways to perform an efficient side channel attack. We discuss potential applications, extensions to other padding schemes and various ways to fix the problem.

Figure: https://www.iacr.org/cryptodb/archive/2002/EUROCRYPT/2850/2850.pdf

CBC Attack

Cryptopals: Exploiting CBC Padding Oracles

This is a write-up of the classic padding oracle attack on CBC-mode block ciphers. If you've done the Cryptopals cryptography challenges, you'll remember it as challenge 17. This is a famous and elegant attack. With it, we will see how even a small data leak (in this case, the presence of a "padding oracle" – defined below) can lead to full plaintext recovery.

Like the Cryptopals challenges, this post is written to be accessible to anyone with an interest in cryptography – no graduate degree required. All you need is patience, focus, and some basic familiarity with the concepts in the following section.

Figure: `https://research.nccgroup.com/2021/02/17/cryptopals-exploiting-cbc-padding-oracles`

CBC Attack

Matthew Green in attacks October 23, 2011 2,314 Words

Attack of the week: XML Encryption

Figure: https://blog.cryptographyengineering.com/2011/10/23/attack-of-week-xml-encryption

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Authenticated CBC Mode

If we check that the CBC encryption was correctly computed, then we do not need to worry about the padding oracle.

Question: What are possible mitigations for CBC?

Possible Mitigations

- Compute a MAC on ptx (✗) or ctx (✓)
- Randomized padding scheme
- Fixed size padding scheme
- Additional randomized delay
- No specific error message

Question: What might go wrong in these cases?

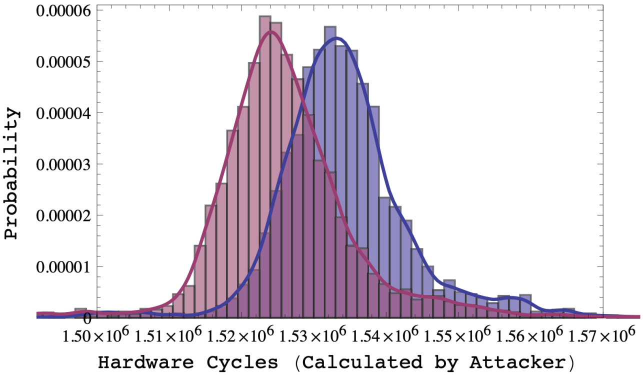

Figure 2. Distribution of timing values (outliers removed) for distinguishing attack on OpenSSL TLS, showing faster processing time in the case of M_0 (in red) compared to M_1 (in blue).

Figure: https://www.ieee-security.org/TC/SP2013/papers/4977a526.pdf

General Solutions

- Always use authenticated encryption
- Avoid CBC mode if possible (use GCM)
- Constant time padding check
- No specific error messages

2013 IEEE Symposium on Security and Privacy

Lucky Thirteen: Breaking the TLS and DTLS Record Protocols

Nadhem J. AlFardan and Kenneth G. Paterson
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Royal Holloway, University of London
Egham, Surrey TW20 0EX, UK
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Figure: https://www.ieee-security.org/TC/SP2013/papers/4977a526.pdf

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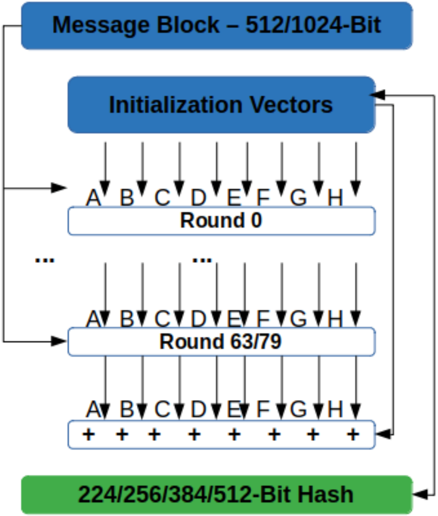
Hashing as MAC

Assume that we are in the following setting:

- Let sk be a fixed size secret
- Let m be a known message
- Let H be a the SHA2 hash function
- Let MAC be $h = H(\mathsf{sk}||m)$

Question 1: Do you remember how SHA2 works?

SHA-2 Process Overview



Hashing as MAC

Assume that we are in the following setting:

- Let sk be a fixed size secret
- Let m be a known message
- Let H be a the SHA2 hash function
- Let MAC be $h = H(\mathsf{sk}||m)$

Question 2: How can we forge $h' = H(\mathsf{sk}||m')$?

Hashing as MAC

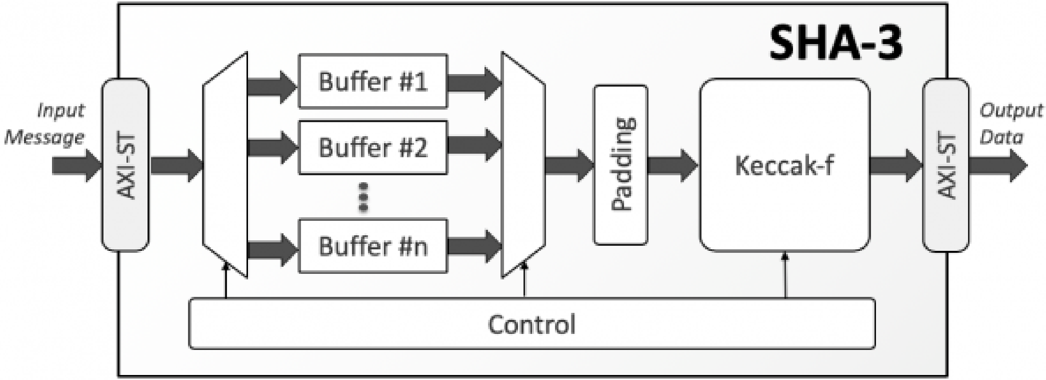
The issue is that SHA2 apply a compression function on blocks of the message using length padding in the end.

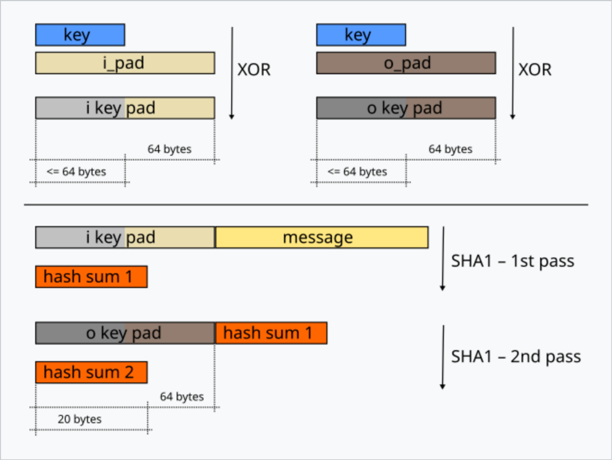
If you know the length of the secret and the message, then you also know the padding, and you can append a message at the end to get a valid hash without knowing the secret.

Hashing as MAC

This attack applies to SHA2, but not to SHA3. SHA3 has a different structure.

Does not apply to HMAC, since it hashes twice to make everything fixed length.


SHA-3
Input
Message
AXI-ST
Buffer #1
Buffer #2
Buffer #n
Padding
Keccak-f
AXI-ST
Output
Data
Control



HMAC-SHA1 generation

Length extension attack

Deep RnD · Follow
4 min read · Aug 16, 2019

12 1

What is length extension?

When a Merkle-Damgård based hash is misused as a message authentication code with construction H(secret ‖ message), and message and the length of secret is known, a length extension attack allows anyone to include extra information at the end of the message and produce a valid hash without knowing the secret. Quick sidebar, before you freak out:

> Since HMAC does not use this construction, HMAC hashes are not prone to length extension attacks.

Figure: https://deeprnd.medium.com/length-extension-attack-bff5b1ad2f70

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Order of Enc and Auth

CPA secure symmetric crypto with input message m:

- SSL/TLS: $a = \mathsf{Auth}_{\mathsf{sk_A}}(\mathsf{m}), \mathsf{c} = \mathsf{Enc}_{\mathsf{sk_E}}(\mathsf{a}, \mathsf{m}), \text{send } \mathsf{c}$
- IPSec: $c = \mathsf{Enc}_{\mathsf{sk_E}}(\mathsf{m}), \mathsf{a} = \mathsf{Auth}_{\mathsf{sk_A}}(\mathsf{c}), \text{send } (\mathsf{a}, \mathsf{c})$
- SSH: $c = \mathsf{Enc}_{\mathsf{sk_E}}(\mathsf{m}), \mathsf{a} = \mathsf{Auth}_{\mathsf{sk_A}}(\mathsf{m}), \text{send } (\mathsf{a}, \mathsf{c})$

Order of Enc and Auth

We refer to these methods as:

- SSL/TLS: authenticate-then-encrypt (AtE)
- IPSec: encrypt-then-authenticate (EtA)
- SSH: encrypt-and-authenticate (E&A)

Order of Enc and Auth

We refer to these methods as:

- SSL/TLS: authenticate-then-encrypt (AtE) (*can* be secure...)
- IPSec: encrypt-then-authenticate (EtA) (proven secure, ✓)
- SSH: encrypt-and-authenticate (E&A) (shown broken, ✗)

Interestingly, AtE is proven secure when using CBC mode.

The Order of Encryption and Authentication for Protecting Communications (Or: How Secure is SSL?)*

Hugo Krawczyk**

Figure: https://iacr.org/archive/crypto2001/21390309.pdf

Questions?