Introduction to Cryptology

6.2 - Authenticated Encryption

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Authenticated Encryption

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Level of secrecy: CCA-security.

Level of integrity: a variant, for encryption schemes, of the message authentication experiment.

Unforgeable Encryption

Let $S = (\text{KeyGen}, \text{Enc}, \text{Dec})$ be an encryption scheme.

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$k \leftarrow \text{KeyGen(n)}$	
$Q = \{\text{queried}\, m\}$	Queries to $\text{Enc}(k, \cdot)$
	Outputs a *forgery* c

$\mathcal{A}$ wins the game, i.e. $\text{PrivK}^{\text{unforg}}_{\mathcal{A},S}(n) = 1$, if, for $m = \text{Dec}(k, c)$, it holds that $m \neq \perp$ and $m \notin Q$.

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Definition

A symmetric-key encryption scheme S is unforgeable if, for every PPT adversary $\mathcal{A}$, $\Pr(\text{PrivK}^{\text{unforg}}_{\mathcal{A},S}(n) = 1) \leq \text{negl}(n)$.

Authenticated Encryption: A Definition

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A symmetric-key encryption scheme is an authenticated encryption scheme is it is both CCA-secure and unforgeable.

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More in general, combining two secure cryptographic schemes does not automatically provide a new secure scheme.

Authenticated Encryption from secure schemes

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In the following, we try to combine:

- a CPA-secure encryption scheme $\Pi_E = (\mathrm{KeyGen}_E, \mathrm{Enc}, \mathrm{Dec})$, and
- a strongly secure MAC $\Pi_M = (\mathrm{KeyGen}_M, \mathrm{Mac}, \mathrm{Verify})$

to obtain authenticated encryption.

How to combine Π_E and Π_M

1. Mac and Enc: compute them independently and in parallel

$$c \leftarrow \text{Enc}(k_1, m) \text{ and } t \leftarrow \text{Mac}(k_2, m)$$

2. Mac then Enc: compute the tag and encrypt it with m

$$t \leftarrow \text{Mac}(k_2, m) \text{ then } c \leftarrow \text{Enc}(k_1, m||t)$$

3. Enc then Mac: compute them sequentially

$$c \leftarrow \text{Enc}(k_1, m) \text{ then } t \leftarrow \text{Mac}(k_2, c)$$

Mac and Enc

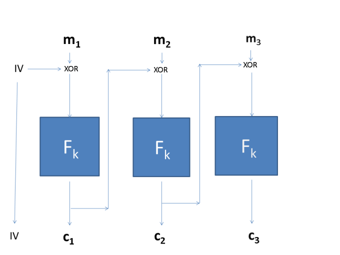
If Mac is deterministic (like for most MACs used in practice), the scheme is not even CPA-secure!

- CPA-security implies CPA-security for multiple encryptions;
- the attacker can submit (m, m) and (m, m') and deduce from the challenge ciphertexts which messages were encrypted.

Mac then Enc

It does not lead to an authenticated encryption in general.

- The CBC-mode encryption is CPA-secure but not CCA-secure, since the padding oracle attack applies.



- If $\mathcal{A}$ distinguishes between decryption and verification failure, they can still exploit the padding oracle attack.

Enc then Mac

The symmetric-key encryption scheme

$$S' = (\text{KeyGen}', \text{Enc}', \text{Dec}')$$

is defined from Π_E and Π_M as follows:

- $k \leftarrow \text{KeyGen}'(n)$: runs KeyGen_E and KeyGen_M on the security parameter n, obtaining k_1, k_2. Then $k = (k_1, k_2)$;
- $c_E \leftarrow \text{Enc}'(k, m)$: computes $c \leftarrow \text{Enc}(k_1, m)$ and then $t \leftarrow \text{Mac}(k_2, c)$. The ciphertext c_E is (c, t).
- $m \leftarrow \text{Dec}'(k, c_E)$:
  - if $\text{Verify}(k_2, c, t) = 1$, then it outputs $\text{Dec}(k_1, c)$;
  - otherwise, it outputs $\perp$.

Enc then Mac

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Sketch of the proof:

- (c, t) is a valid ciphertext if $\text{Verify}(k_2, c, t) = 1$;
- $\mathcal{A}$ cannot generate a new ciphertext (i.e. not obtained from the encryption oracle) since Π_M is strongly secure;
- hence, S' is unforgeable and $\mathcal{A}$ cannot benefit from the decryption oracle of the CCA indistinguishable experiment;
- therefore, CPA-security of Π_E is enough.

Authenticated Encryption: Possible Attacks

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- Reflection attack: change the direction of a message resending it to the sender instead of the receiver.

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Counters to prevent the first attack; different encryption keys for different directions, i.e. $K_{A \to B} \neq K_{B \to A}$, for the third.

Further Reading I

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