

1. An attacker intercepts the following ciphertext (hex encoded): 1 / 1 point

20814804c1767293bd9f1d9cab3bc3e7ac1e37bfb15599e5f40eef805488281d

He knows that the plaintext is the ASCII encoding of the message "Pay Bob 100\$" (excluding the quotes). He also knows that the cipher used is CBC encryption with a random IV using AES as the underlying block cipher.

Show that the attacker can change the ciphertext so that it will decrypt to "Pay Bob 500\$". What is the resulting ciphertext (hex encoded)?

This shows that CBC provides no integrity.

20814804c1767293bd9f1d9cab3bc3e7ac1e37bfb15599e5f40eef805488281d

Correct
 You got it!

2. Let (E, D) be an encryption system with key space K , message 1 / 1 point

space $\{0, 1\}^n$ and ciphertext space $\{0, 1\}^s$. Suppose (E, D)

provides authenticated encryption. Which of the following systems

provide authenticated encryption: (as usual, we use \parallel to denote

string concatenation)

☐ $E'(k, m) = (E(k, m), 0)$ and

$D'(k, (c, b)) = D(k, c)$

☒ $E'(k, m) = E(k, m \oplus 1^n)$ and

$D'(k, c) = \begin{cases} D(k, c) \oplus 1^n & \text{if } D(k, c) \neq \perp \\ \perp & \text{otherwise} \end{cases}$

Correct

(E', D') provides authenticated encryption because an attack on (E', D')

directly gives an attack on (E, D) .

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☐ $E'(k, m) = E(k, m)$ and

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3. If you need to build an application that needs to encrypt multiple 1 / 1 point

messages using a single key, what encryption

method should you use? (for now, we ignore the question of key generation

and management)

☐ use a standard implementation of CBC encryption with

a random IV.

☐ implement Encrypt-and-MAC yourself

☐ implement MAC-then-Encrypt yourself

☒ use a standard implementation of one of the authenticated

encryption modes GCM, CCM, EAX or OCB.

Correct

4. Let (E, D) be a symmetric encryption system with message space M (think 1 / 1 point

of M as only consisting for short messages, say 32 bytes).

Define the following MAC (S, V) for messages in M :

$S(k, m) := E(k, m) \quad ; \quad V(k, m, t) := \begin{cases} 1 & \text{if } D(k, t) = m \\ 0 & \text{otherwise} \end{cases}$

What is the property that the encryption system (E, D) needs to satisfy

for this MAC system to be secure?

☒ ciphertext integrity

☐ perfect secrecy

☐ semantic security

☐ semantic security under a chosen plaintext attack

Correct

Indeed, ciphertext integrity prevents existential

forgery under a chosen message attack.

5. In [Key Derivation](#) we discussed how to derive session keys 1 / 1 point

from a shared secret. The problem is what to do when the shared

secret is non-uniform. In this question we show that using a PRF with

a *non-uniform* key may result in non-uniform values. This shows that

session keys cannot be derived by directly using a *non-uniform*

secret as a key in a PRF. Instead, one has to use a key derivation

function like HKDF.

Suppose k is a *non-uniform* secret key sampled from the key space $\{0, 1\}^{256}$.

In particular, k is sampled uniformly from the set of all keys whose most significant

128 bits are all 0. In other words, k is chosen uniformly from a small subset of the key space. More precisely,

for all $c \in \{0, 1\}^{256} : \Pr[k = c] = \begin{cases} 1/2^{128} & \text{if } \text{MSB}_{128}(c) = 0^{128} \\ 0 & \text{otherwise} \end{cases}$

Let $F(k, x)$ be a secure PRF with input space $\{0, 1\}^{256}$. Which

of the following is a secure PRF when the key k is uniform in the

key space $\{0, 1\}^{256}$, but is insecure when the key is sampled from the *non-uniform*

distribution described above?

☒ $F'(k, x) = \begin{cases} F(k, x) & \text{if } \text{MSB}_{128}(k) \neq 0^{128} \\ 0^{256} & \text{otherwise} \end{cases}$

☐ $F'(k, x) = \begin{cases} F(k, x) & \text{if } \text{MSB}_{128}(k) = 0^{128} \\ 0^{256} & \text{otherwise} \end{cases}$

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Correct

$F'(k, x)$ is a secure PRF because for a uniform key k the

probability that $\text{MSB}_{128}(k) = 0^{128}$ is negligible.

However, for the "non-uniform" key k this PRF always outputs 0

and is therefore completely insecure. This PRF cannot be used as a

key derivation function for the distribution of keys described in the problem.

6. In what settings is it acceptable to use *deterministic* authenticated 1 / 1 point

encryption (DAE) like SIV?

☐ to individually encrypt many packets in a voice conversation with a single key.

☐ to encrypt many records in a database with a single key when the same record may repeat multiple times.

☒ when messages have sufficient structure to guarantee that all

messages to be encrypted are unique.

☐ when a fixed message is repeatedly encrypted using a single key.

Correct

Deterministic encryption is safe to use when the message/key pair

is never used more than once.

7. Let $E(k, x)$ be a secure block cipher. Consider the following 1 / 1 point

tweakable block cipher:

$E'((k_1, k_2), t, x) = E(k_1, x) \oplus E(k_2, t)$.

Is this tweakable block cipher secure?

☒ no because for $t \neq t'$ we have

$E'((k_1, k_2), t, 0) \oplus E'((k_1, k_2), t, 1) = E'((k_1, k_2), t', 0) \oplus E'((k_1, k_2), t', 1)$

☐ no because for $t \neq t'$ we have

$E'((k_1, k_2), t, 0) \oplus E'((k_1, k_2), t', 1) = E'((k_1, k_2), t', 1) \oplus E'((k_1, k_2), t', 0)$

☐ no because for $x \neq x'$ and $t \neq t'$ we have

$E'((k_1, k_2), t, x) \oplus E'((k_1, k_2), t', x) = E'((k_1, k_2), t, x') \oplus E'((k_1, k_2), t', x)$

☐ no because for $x \neq x'$ we have

$E'((k_1, k_2), 0, x) \oplus E'((k_1, k_2), 0, x) = E'((k_1, k_2), 0, x') \oplus E'((k_1, k_2), 0, x')$

☐ yes, it is secure assuming E is a secure block cipher.

Correct

since this relation holds, an attacker can make 4 queries to E'

and distinguish E' from a random collection of one-to-one functions.

8. In [Format Preserving Encryption](#) we discussed format preserving encryption 1 / 1 point

which is a PRP on a domain $\{0, \dots, s - 1\}$ for some pre-specified

value of s .

Recall that the construction we presented worked in two steps,

where the second step worked by iterating the PRP until the output

fell into the set $\{0, \dots, s - 1\}$.

Suppose we try to build a format preserving credit card encryption

system from AES using "only" the second step. That is, we start with

a PRP with domain $\{0, 1\}^{128}$ from which we want to build a PRP

with domain 10^{16} . If we only used step (2), how many iterations of

AES would be needed in expectation for each evaluation of the PRP

with domain 10^{16} ?

☐ 2^{128}

☒ $2^{128} / 10^{16} \approx 3.4 \times 10^{22}$

☐ 10^{16}

☐ 2

Correct

On every iteration we have a probability of $10^{16} / 2^{128}$ of falling

into the set $\{0, \dots, 10^{16}\}$ and therefore in expectation we

will need $2^{128} / 10^{16}$ iterations. This should explain why

step (1) is needed.

9. Let (E, D) be a secure tweakable block cipher. 1 / 1 point

Define the following MAC (S, V) :

$S(k, m) := E(k, m, 0) \quad ; \quad V(k, m, \text{tag}) := \begin{cases} 1 & \text{if } E(k, m, 0) = \text{tag} \\ 0 & \text{otherwise} \end{cases}$

In other words, the message m is used as the tweak and the plaintext given to E is always set to 0.

Is this MAC secure?

☒ yes

☐ no

☐ it depends on the tweakable block cipher.

Correct

A tweakable block cipher is indistinguishable from a

collection of random permutations. The chosen message attack on the

MAC gives the attacker the image of 0 under a number of the

permutations in the family. But that tells the attacker nothing about

the image of 0 under some other member of the family.

10. In [CBC Padding Attacks](#) we discussed padding oracle attacks. These chosen-ciphertext attacks can break poor 1 / 1 point

implementations of MAC-then-encrypt.

Consider a system that implements MAC-then-encrypt where encryption is done using CBC with a random IV using AES as the block cipher. Suppose the system is vulnerable to a padding oracle attack. An attacker intercepts a 64-byte ciphertext c (the first 16 bytes of c are the IV and the remaining 48 bytes are the encrypted payload). How many chosen ciphertext queries would the attacker need in the worst case in order to decrypt the entire 48 byte payload? Recall that padding oracle attacks decrypt the payload one byte at a time.

☐ 48

☐ 1024

☐ 256

☐ 16384

☒ 12288

Correct

Correct. Padding oracle attacks decrypt the payload one byte at a time. For each byte the attacker needs no more than 256 guesses in the worst case. Since there are 48 bytes total, the number queries needed is $256 \times 48 = 12288$.