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Week 4 - Problem Set

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

20814804c1767293b99f1d9cab3bc3e7 ac1e37bfb15599e5f40eef805488281d

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.

20814804c1767293bd9f1d9cab3bc3e7 ac1e37bfb15599e5f40eef805488281d

Correct
You got it!

2. Let (E,D) be an encryption system with key space K, message space $\{0,1\}^n$ and ciphertext space $\{0,1\}^s$. Suppose (E,D) provides authenticated encryption. Which of the following systems provide authenticated encryption: 0 / 1 point

(as usual, we use $\|$ to denote string concatenation)

- [x] $E'(k,m) = (E(k,m),\ 0)$ and

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

This should not be selected
This system does not provide ciphertext integrity.

The attacker queries for $E'(k,0^n)$ to obtain $(c,0)$.

It then outputs $(c,1)$ and wins the ciphertext integrity game.

- [x] $E'(k,m) = (E(k,m),\ E(k,m))$ and

$$D'(k,\ (c_1,c_2)\ ) = \begin{cases} D(k,c_1) & \text{if } D(k,c_1) = D(k,c_2) \\ \perp & \text{otherwise} \end{cases}$$

This should not be selected
This system does not provide ciphertext integrity. To see why, recall

that authenticated encryption (without a nonce) must be randomized

to provide CPA security. Therefore, $E'(k,m) = (c_1,c_2)$ will likely

output a distinct ciphertext pair $c_1 \neq c_2$. The attacker can then

output the ciphertext (c_1,c_1) and win the ciphertext integrity game.

- [x] $E'(k,m) = (E(k,m),\ 0)$ and

$$D'(k,\ (c,b)\ ) = \begin{cases} D(k,c) & \text{if } b=0 \\ \perp & \text{otherwise} \end{cases}$$

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

directly gives an attack on (E,D).

- [x] $E'(k,m) = E(k, m \bigoplus 1^n)$ and

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

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

directly gives an attack on (E,D).

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)

- ( ) implement OCB by yourself
- (•) use a standard implementation of one of the authenticated

  encryption modes GCM, CCM, EAX or OCB.
- ( ) use a standard implementation of randomized

  counter mode.
- ( ) use a standard implementation of CBC encryption with

  a random IV.

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?

- (•) authenticated encryption
- ( ) semantic security under a deterministic chosen plaintext attack
- ( ) semantic security
- ( ) semantic security under a chosen plaintext attack

Correct
Indeed, authenticated encryption implies ciphertext

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

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?

- (•) $F'(k,x) = \begin{cases} F(k,x) & \text{if } \mathrm{MSB}_{128}(k) \neq 0^{128} \\ 0^{256} & \text{otherwise} \end{cases}$
- ( ) $F'(k,x) = \begin{cases} F(k,x) & \text{if } \mathrm{MSB}_{128}(k) \neq 1^{128} \\ 0^{256} & \text{otherwise} \end{cases}$
- ( ) $F'(k,x) = F(k,x)$
- ( ) $F'(k,x) = \begin{cases} F(k,x) & \text{if } \mathrm{MSB}_{128}(k) \neq 1^{128} \\ 1^{256} & \text{otherwise} \end{cases}$

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

probability that $\mathrm{MSB}_{128}(k) = 0^{128}$ 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?

- (•) when messages are chosen at random from a large enough space so that

  messages are unlikely to repeat.
- ( ) when a fixed message is repeatedly encrypted using a single key.
- ( ) 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.

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:

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

Is this tweakable block cipher secure?

- (•) no because for $t \neq t'$ we have

  $E'((k_1,k_2),t,0) \bigoplus E'((k_1,k_2),t,1) = E'((k_1,k_2),t',0) \bigoplus E'((k_1,k_2),t',1)$
- ( ) no because for $t \neq t'$ we have

  $E'((k_1,k_2),t,0) \bigoplus E'((k_1,k_2),t',1) = E'((k_1,k_2),t',1) \bigoplus E'((k_1,k_2),t',0)$
- ( ) no because for $x \neq x'$ and $t \neq t'$ we have

  $E'((k_1,k_2),t,x) \bigoplus E'((k_1,k_2),t',x) = E'((k_1,k_2),t,x') \bigoplus E'((k_1,k_2),t',x)$
- ( ) no because for $x \neq x'$ we have

  $E'((k_1,k_2),0,x) \bigoplus E'((k_1,k_2),0,x) = E'((k_1,k_2),0,x') \bigoplus E'((k_1,k_2),0,x')$
- ( ) 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 $\{0,\ldots,s-1\}$ 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 $\{0,\ldots,s-1\}$.

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}?

- (•) $2^{128}/10^{16} \approx 3.4 \times 10^{22}$
- ( ) $10^{16}/2^{128}$
- ( ) 2^{128}
- ( ) 2

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

into the set $\{0,\ldots,10^{16}\}$ 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):

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

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?

- ( ) it depends on the tweakable block cipher.
- ( ) no
- (•) yes

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 implementations of MAC-then-encrypt. 1 / 1 point

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.

- (•) 12288
- ( ) 256
- ( ) 1024
- ( ) 16384
- ( ) 48

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 $256 \times 48 = 12288$