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Feedback — Week 4 - Problem Set

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You submitted this homework on **Tue 17 Feb 2015 1:51 PM CET**. You got a score of **8.50** out of **10.00**. You can attempt again in 10 minutes.

Question 1

An attacker intercepts the following ciphertext (hex encoded):

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.

You entered:

20814804c1767293bd9f1d9cab3bc3e7
ac1e37bfb15599e5f40eef805488281d

Your Answer		Score	Explanation
20814804c1767293bd9f1d9cab3bc3e7 ac1e37bfb15599e5f40eef805488281d	✔	1.00	You got it!
Total		1.00 / 1.00	

Question 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: (as usual, we use || to denote string concatenation)

Your Answer		Score	Explanation
$E'(k,m) = \big(E(k,m),\ 0\big)$ and $D'(k,\ (c,b)\ ) = \begin{cases} D(k,c) & \text{if } b=0 \\ \perp & \text{otherwise} \end{cases}$	✖	0.00	(E', D') provides authenticated encryption because an attack on (E', D') directly gives an attack on (E, D).
$E'(k,m) = \big(E(k,m),\ 0\big)$ and $D'(k,\ (c,b)\ ) = D(k,c)$	✔	0.25	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.
$E'(k,m) = E(k,m) \bigoplus 1^s$ and $D'(k,c) = D(k, c \bigoplus 1^s)$	✖	0.00	(E', D') provides authenticated encryption because an attack on (E', D') directly gives an attack on (E, D).
$E'(k,m) = \big(E(k,m),\ E(k,m)\big)$ and $D'(k,\ (c_1,c_2)\ ) = \begin{cases} D(k,c_1) & \text{if } D(k,c_1) = D(k,c_2) \\ \perp & \text{otherwise} \end{cases}$	✔	0.25	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.

Total	0.50 / 1.00

Question 3

If you need to build an application that needs to encrypt multiple messages using a single key, what encryption method should you use? (for now, we ignore the question of key generation and management)

Your Answer		Score	Explanation
implement MAC-then-Encrypt yourself			
use a standard implementation of randomized counter mode.			
use a standard implementation of CBC encryption with a random IV.			
use a standard implementation of one of the authenticated encryption modes GCM, CCM, EAX or OCB.	✔	1.00	
Total		1.00 / 1.00	

Question 4

Let (E, D) be a symmetric encryption system with message space M (think 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?

Your Answer		Score	Explanation
authenticated encryption	✔	1.00	Indeed, authenticated encryption implies ciphertext integrity which prevents existential forgery under a chosen message attack.
semantic security under			

a deterministic chosen plaintext attack

- perfect secrecy
- semantic security

Total	1.00 / 1.00

Question 5

In lecture 8.1 we discussed how to derive session keys 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,

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

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?

Your Answer		Score	Explanation
$F'(k,x) = \begin{cases} F(k,x) & \text{if } \mathrm{MSB}_{128}(k) = 0^{128} \\ 1^{256} & \text{otherwise} \end{cases}$			
$F'(k,x) = \begin{cases} F(k,x) & \text{if } \mathrm{MSB}_{128}(k) \neq 0^{128} \\ 1^{256} & \text{otherwise} \end{cases}$	✔	1.00	$F'(k,x)$ 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 1 and is therefore completely insecure. This PRF cannot be used as a

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

$F'(k,x) = F(k,x)$		
$F'(k,x) = \begin{cases} F(k,x) & \text{if } \mathrm{MSB}_{128}(k) \neq 1^{128} \\ 0^{256} & \text{otherwise} \end{cases}$		
Total	1.00 / 1.00	

Question 6

In what settings is it acceptable to use *deterministic* authenticated encryption (DAE) like SIV?

Your Answer		Score	Explanation
when a fixed message is repeatedly encrypted using a single key.			
to individually encrypt many packets in a voice conversation with a single key.			
when messages are chosen at random from a large enough space so that messages are unlikely to repeat.	✔	1.00	Deterministic encryption is safe to use when the message/key pair is never used more than once.
to encrypt many records in a database with a single key when the same record may repeat multiple times.			
Total		1.00 / 1.00	

Question 7

Let $E(k,x)$ be a secure block cipher. Consider the following tweakable block cipher:

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

Is this tweakable block cipher secure?

Your Answer		Score	Explanation
◉ no because for $t \neq t'$ we have $E'((k_1,k_2),t,0) \bigoplus E'((k_1,k_2),t',1) = E'((k_1,k_2),t',1) \bigoplus E'((k_1,k_2),t'$	✖	0.00	This relation doesn't hold for E'.
○ no because for $x \neq x'$ and $t \neq t'$ we have $E'((k_1,k_2),t,x) \bigoplus E'((k_1,k_2),t',x) = E'((k_1,k_2),t,x') \bigoplus E'((k_1,k_2),t'$			
○ no because for $x \neq x'$ we have $E'((k_1,k_2),0,x) \bigoplus E'((k_1,k_2),1,x) = E'((k_1,k_2),0,x') \bigoplus E'((k_1,k_2),1$			
○ no because for $x \neq x'$ we have $E'((k_1,k_2),0,x) \bigoplus E'((k_1,k_2),0,x) = E'((k_1,k_2),0,x') \bigoplus E'((k_1,k_2),0$			
○ yes, it is secure assuming E is a secure block cipher.			
Total		0.00 / 1.00	

Question 8

In lecture 8.5 we discussed format preserving encryption 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}?

Your Answer		Score	Explanation
◉ $2^{128}/10^{16} \approx 3.4 \times 10^{22}$	✔	1.00	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.
○ 2			

○ 10^{16}

○ $10^{16}/2^{128}$

Total	1.00 / 1.00

Question 9

Let (E, D) be a secure tweakable block cipher. 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?

Your Answer		Score	Explanation
○ it depends on the tweakable block cipher.			
◉ yes	✔	1.00	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.
○ no			
Total		1.00 / 1.00	

Question 10

In Lecture 7.6 we discussed padding oracle attacks. These chosen-ciphertext attacks can break poor 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.

Your Answer		Score	Explanation
◉ 12288	✔	1.00	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 $256 \times 48 = 12288$.
○ 1024			
○ 12240			
○ 256			
Total		1.00 / 1.00	