Network Information Security

Lecture four: stream cipher

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Symmetric Ciphers: definition

Def: a **cipher** defined over $(\mathcal{K}, \mathcal{M}, \mathcal{C})$

is a pair of "efficient" algs (***E***, ***D***) where

$E: \mathcal{K} \times \mathcal{M} \to \mathcal{C}$, $D: \mathcal{K} \times \mathcal{C} \to \mathcal{M}$

s.t. $\forall m \in \mathcal{M}, k \in \mathcal{K}: D(k, E(k, m)) = m$

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Wrap up

- $(\mathcal{E}, \mathcal{D}, \mathcal{M}, \mathcal{K}, \mathcal{C})$ (密码系统五元组)
- Classical cipher
  - Substitution cipher
    - Monoalphabetic cipher — Caesar cipher
    - Polyalphabetic cipher — Vigenère cipher
- How to break?
  - Brute force
  - Frequency analysis

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Vigenère Cipher exercise

Try to encode "UNDERATTACK" using the key CAR

message:	**U**	**N**	**D**	**E**	**R**	**A**	**T**	**T**	**A**	**C**	**K**
repeated keyword:	C	A	R	C	A	R	C	A	R	C	A
encoded message:	**W**	**N**									

	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
A	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z
B	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A
C	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B
D	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C
E	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D
F	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E
G	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F
H	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G
I	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H
J	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I
K	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J
L	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K
M	M	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L
N	N	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M
O	O	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N
P	P	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O
Q	Q	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P
R	R	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q
S	S	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R
T	T	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S
U	U	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T
V	V	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U
W	W	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V
X	X	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W
Y	Y	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X
Z	Z	A	B	C	D	E	F	G	H	I	J	K	L	M	N	O	P	Q	R	S	T	U	V	W	X	Y

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Transposition Cipher (置换密码)

- Rearrange letters in plaintext to produce ciphertext
- Example: **Rail-Fence Cipher (栅栏密码)**
  - Plaintext is **HELLO WORLD**
  - Rearrange as
    HLOOL
    ELWRD
  - Ciphertext is **HLOOL ELWRD**
  - Question: `What is the key?`

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- Encode the phrase WE NEED YOUR HELP using the Rail Fence cipher.

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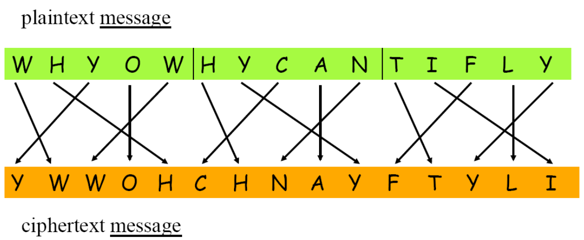
Transposition cipher

- Transposition cipher example #1:
  - Permute each successive block of 5 letters in the message according to position offset <+1, +3, -2, 0, -2>



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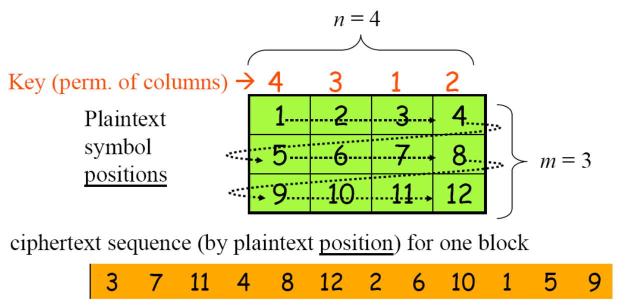
Transposition cipher (cont'd)

- Transposition cipher example #2：
  - Arrange plaintext in blocks of n columns and m rows
  - Then permute columns in a block according to a key K



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Transposition cipher (cont'd)

- A longer example: plaintext =
- "ATTACK POSTPONED UNTIL TWO AM"

Key:	4	3	1	2	5	7	6
plaintext	A	T	T	A	C	K	P
	O	S	T	P	O	N	E
	D	U	N	T	I	L	T
	W	O	A	M	X	Y	Z

ciphertext

TTNA APTM TSUO AODW COIX PETZ KNLY

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Classical Cryptography（经典加密方法）

- Two basic types of classical ciphers
  - Transposition ciphers (置换密码)
  - Substitution ciphers (替换密码)
  - Combinations are called *product ciphers* (组合密码)

- Transposition cipher: rearranges the characters in the plaintext to form the ciphertext. The letters are not changed.
- Substitution cipher: change characters in the plaintext to produce the ciphertext.

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outline

- One time pad (一次密码簿)
- Perfect secrecy – Shannon
- Stream cipher (流密码)

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How to increase the secrecy of cipher?

Randomness(随机性)

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One time pad

If the ... ng as
the me ... comes
kno... used

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Vernam cipher

- AT&T公司的Gilbert Vernam在1917年发明的一种加密方案。

$$c_i = p_i \oplus k_i$$

$$p_i = c_i \oplus k_i$$

- Use a very long but repeating keyword.

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Truth table of XOR

x⊕y	x	y

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OTP：one time pad

- Joseph Mauborgne proposed an improvement on Vernam cipher.
  - Key is as long as the message.
  - Key is only used one time.

video One time pad

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The One Time Pad (Vernam 1917)

$D(k, E(k, m)) = m$

First example of a "secure" cipher

$k \in \mathcal{K}$

$\mathcal{M} = \mathcal{C} = \{0,1\}^n$, $\mathcal{K} = \{0,1\}^n$

$E(k, m) = k \oplus m$

$D(k, c) = k \oplus c$

key = (random bit string as long the message)

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The One Time Pad (Vernam 1917)

$D(k, E(k,m)) = D(k, k \oplus m) = (k \oplus k) \oplus m = 0 \oplus m = m$

$c := E(k,m) = k \oplus m$

$D(k,c) = k \oplus c$

msg: 0 1 1 0 1 1 1

key: 1 0 1 1 0 1 0 $\oplus$

CT:

Try to verify the consistency of One Time Pad.

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One time pad

$M = C = \{0, 1\}^n$

$K = \{0,1\}^n$

$E(k, m) = k \oplus m$

$D(k, c) = k \oplus c$

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Perfect secrecy

Def: A cipher (***E***, ***D***) over $(\mathcal{K}, \mathcal{M}, \mathcal{C})$ has **perfect secrecy** if

$\forall m_0, m_1 \in \mathcal{M} \quad (|m_0| = |m_1|)$ and $\forall c \in \mathcal{C}$

$\boxed{\Pr[\mathbf{E}(k, m_0) = c] = \Pr[\mathbf{E}(k, m_1) = c]}$ where $k \leftarrow \mathcal{K}$

Basic idea: Cipher text (CT) should reveal(揭示) no information about plain text (PT).

如果我是一个攻击者，我截取了一段密文，c，这段密文 c 对应的明文是 m_0 的概率与对应的明文是 m_1 的概率相同。

唯密文攻击

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One time pad has perfect secrecy

To proof $Pr[\, \boldsymbol{E(k, m_0) = c} \,] = Pr[\, \boldsymbol{E(k, m_1) = c} \,]$

$\forall$m,c:

$Pr[\boldsymbol{E(k,m) = c}]$ = (#keys k∈K s.t. E(k,m)=c)/|K|

So, if #{k∈K s.t. E(k,m)=c} = const,

We can proof cipher has perfect secrecy.

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One time pad has perfect secrecy

For OTP:

$\forall$ m, c:

If E(k, m) = c

→ k ⊕ m = c

→ k = m ⊕ c

→ # (k∈K s.t. E(k,m)=c) = 1

→ OTP has perfect secrecy.■

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单选题 1分 设置

You are given a message (*m*) and its OTP encryption (*c*).

Can you compute the OTP key from *m* and *c* ?

- A No, I cannot compute the key.
- B Yes, the key is $k = m \oplus c$.
- C I can only compute half the bits of the key.
- D Yes, the key is $k = m \oplus m$.

提交

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Drawbacks of OTP

- **Truly Random**
- **As long as the message**
- **Secure exchange of OTP**
- **One time only use of the key**

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The bad news …

Thm: perfect secrecy $\Rightarrow$ $|\mathcal{K}| \geq |\mathcal{M}|$

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To make OTP practical:

Stream Cipher

Basic idea: replace “random” key by “pseudorandom” key

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Stream Ciphers: making OTP practical

idea: replace “random” key by “pseudorandom” key

PRG: Pseudo Random Generator is a function, G

$$G: \{0, 1\}^s \rightarrow \underbrace{\{0,1\}^n}_{\textbf{Seed space}}, \quad n >> s$$

Efficiently deterministic algorithm

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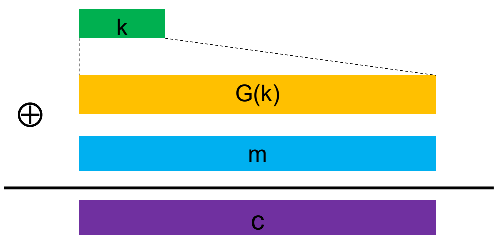
Stream Ciphers: making OTP practical



$c = E(k, m) := m \oplus G(k)$

$d = E(k, c) := c \oplus G(k)$

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单选题 1分

设置

Can a stream cipher have perfect secrecy?

- A Yes, if the PRG is really “secure”
- B No, there are no ciphers with perfect secrecy
- C Yes, every cipher has perfect secrecy
- D No, since the key is shorter than the message

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Attacks on OTP and stream ciphers

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Attack 1: two time pad is insecure !!

Never use stream cipher key more than once !!

$$C_1 \leftarrow m_1 \oplus PRG(k)$$
$$C_2 \leftarrow m_2 \oplus PRG(k)$$

Eavesdropper does:

$$C_1 \oplus C_2 \rightarrow m_1 \oplus m_2$$

Enough redundancy in English and ASCII encoding that:

$$m_1 \oplus m_2 \rightarrow m_1 , m_2$$

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Real world examples

- Project Venona
  - 1941 to 1946, decrypted about 3000 messages
- MS-PPTP (windows NT, point to point transfer protocol):

$[m_1||m_2||m_3] \oplus G(k)$ $[s_1||s_2||s_3] \oplus G(k)$

Need different keys for C→S and S→C

The shared key is actually a pair of keys: (Kc→s and Ks→c)
Both sides have these pair of keys.

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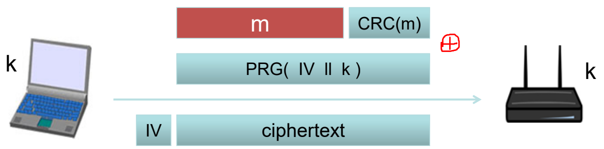
Real world examples

802.11b WEP:



Length of IV: 24 bits

- Repeated IV after $2^{24} \approx$ 16M frames
- On some 802.11 cards: IV resets to 0 after power cycle

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- 假设一个繁忙的**AP**（无线访问点），以**11Mbps**的速度发送大小为**1500bytes**的包，大约多长时间**IV**会耗光？

1500*8/(11*10^6)*2^24 = 18000秒，约为5 hours

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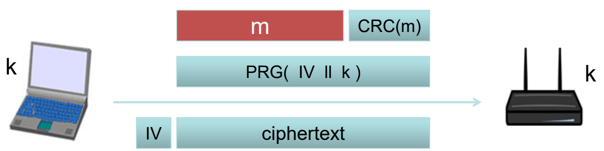
Avoid related keys

802.11b WEP:



key for frame #1: (1 ll k)

key for frame #2: (2 ll k)

⋮

FMS 2001 → can recover k after 10^6 frames, recent attacks ≈ 40,000 frames

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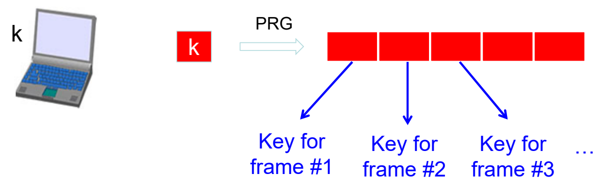
A better construction



⇒ now each frame has a pseudorandom key

better solution: use stronger encryption method (as in WPA2)

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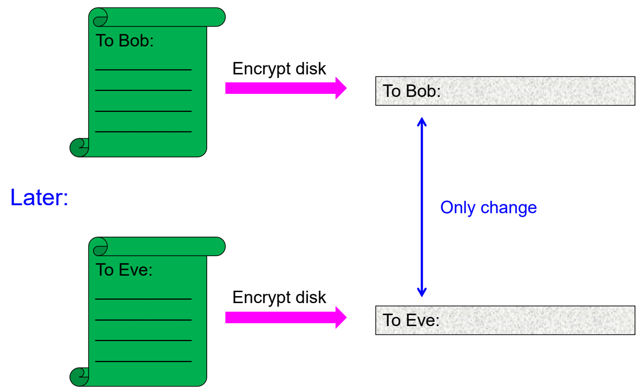
Yet another example: disk encryption



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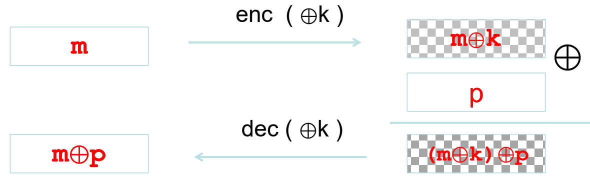
Attack 2: no integrity (OTP is malleable)



Modifications to ciphertext are undetected and have **predictable** impact on plaintext

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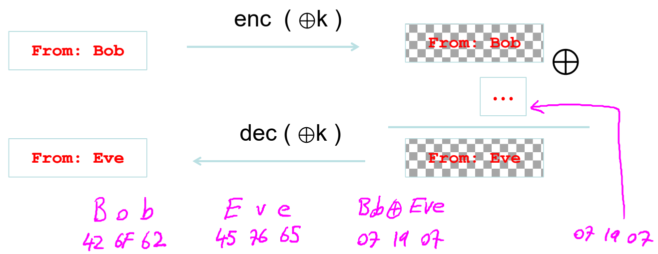
Attack 2: no integrity (OTP is malleable)



Modifications to ciphertext are undetected and have predictable impact on plaintext

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Real world stream ciphers

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RC4 stands for the fourth cipher designed by Ron Rivest (Rivest Cipher 4).

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