Stream Ciphers and Block Ciphers

Guest Lecture for 2WC12 Cryptography I - Fall 2011

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Introduction

Stream Ciphers:

- symmetric-key cipher
- state-driven: operates on arbitrary message length
- commonly used stream ciphers: A5/1 and A5/2 (GSM), RC4 (SSL, WEP), eSTREAM Project

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Synchronous Stream Ciphers:

Given key K and initial state σ_0:

state:	σ_{i+1}	$=$	$f(\sigma_i, K)$	with next-state function f
key stream:	z_i	$=$	$g(\sigma_i, K)$	with key-stream function g
cipher stream:	c_i	$=$	$h(z_i, m_i)$	with output function h

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Self-Synchronizing Stream Ciphers:

Given key K and initial state σ_0:

state:	σ_{i+1}	$=$	$(c_i, c_{i-1}, \ldots c_{i-t+1})$	
key stream:	z_i	$=$	$g(\sigma_i, K)$	with key-stream function g
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An n-bit block cipher is a function $E : \{0,1\}^n \times \mathfrak{K} \rightarrow \{0,1\}^n$.
For each fixed $K \in \mathfrak{K}$ the map

$$E_K : \{0,1\}^n \rightarrow \{0,1\}^n, M \mapsto E(M,K)$$

is invertible (bijective) with inverse $E_K^{-1} : \{0,1\}^n \rightarrow \{0,1\}^n$.

From Block Ciphers to Stream Ciphers

Mode of Operation:

- Electronic codebook (ECB) mode:
  - Encryption:
    obtain ciphertext $C_1, \ldots, C_t$ as $C_i = E_K(M_i), i = 1 \ldots t$
  - Decryption:
    obtain plaintext $M_1, \ldots, M_t$ as $M_i = E_K^{-1}(C_i), i = 1 \ldots t$

From Block Ciphers to Stream Ciphers

Mode of Operation:

- Electronic codebook (ECB) mode
- Cipher-block chaining (CBC) mode:
  Use a (non-secret) initialization vector (IV) of length n bits.
  - Encryption:
    obtain ciphertext $C_1, \ldots, C_t$ as
    $C_i = E_K(M_i \oplus C_{i-1}), i = 1 \ldots t, C_0 = IV$
  - Decryption:
    obtain plaintext $M_1, \ldots, M_t$ as
    $M_i = E_K^{-1}(C_i) \oplus C_{i-1}, i = 1 \ldots t, C_0 = IV$

From Block Ciphers to Stream Ciphers

Mode of Operation:

- Electronic codebook (ECB) mode
- Cipher-block chaining (CBC) mode
- Cipher feedback (CFB) mode:
  Use a (non-secret) initialization vector (IV) of length n bits.
  - Encryption:
    obtain ciphertext $C_1, \ldots, C_t$ as
    $C_i = E_K(C_{i-1}) \oplus M_i, i = 1 \ldots t, C_0 = IV$
  - Decryption:
    obtain plaintext $M_1, \ldots, M_t$ as
    $M_i = E_K(C_{i-1}) \oplus C_i, i = 1 \ldots t, C_0 = IV$

From Block Ciphers to Stream Ciphers

Mode of Operation:

- Electronic codebook (ECB) mode
- Cipher-block chaining (CBC) mode
- Cipher feedback (CFB) mode
- Output feedback (OFB) mode:
  Use a (non-secret) initialization vector (IV) of length n bits.
  - Encryption:
    obtain ciphertext $C_1, \ldots, C_t$ as
    $C_i = O_i \oplus M_i, i = 1 \ldots t, O_i = E_K(O_{i-1}), O_0 = IV$
  - Decryption:
    obtain plaintext $M_1, \ldots, M_t$ as
    $M_i = O_i \oplus C_i, i = 1 \ldots t, O_i = E_K(O_{i-1}), O_0 = IV$

From Block Ciphers to Stream Ciphers

Mode of Operation:

- Electronic codebook (ECB) mode
- Cipher-block chaining (CBC) mode
- Cipher feedback (CFB) mode
- Output feedback (OFB) mode
- Counter (CTR) mode:
  Use a (non-secret) initialization vector (IV) of length n bits.
  - Encryption:
    obtain ciphertext $C_1, \ldots, C_t$ as
    $C_i = E_K(N_i) \oplus M_i, i = 1 \ldots t, N_i = N_{i-1} + 1 \mod 2^n, N_0 = IV$
  - Decryption:
    obtain plaintext $M_1, \ldots, M_t$ as
    $M_i = E_K(N_i) \oplus C_i, i = 1 \ldots t, N_i = N_{i-1} + 1 \mod 2^n, N_0 = IV$

Properties of the Block-Cipher Modes of Operation

- ECB is considered insecure if applied to more than one block: Identical input blocks are mapped to identical output blocks.
- In CBC and CFB mode, the last ciphertext block C_t depends on all message blocks $M_1, \ldots, M_t$, in ECB, OFB, and CTR mode each block of ciphertext C_i only on message block M_i.
- CBC, CFB, and OFB encryption can not be performed in parallel on several blocks, ECB and CTR encryption can. CBC and CFB decryption also can be performed in parallel.
- Only ECB and CTR allow random access to the ciphertext.
- CBC and ECB require padding of the input to a multiple of the block size, CFB, OFB, and CTR don't.
- For OFB, CFB, and CTR mode each two messages encrypted with he same key must use a different IV.
- Most widely used modes are CBC and CTR.

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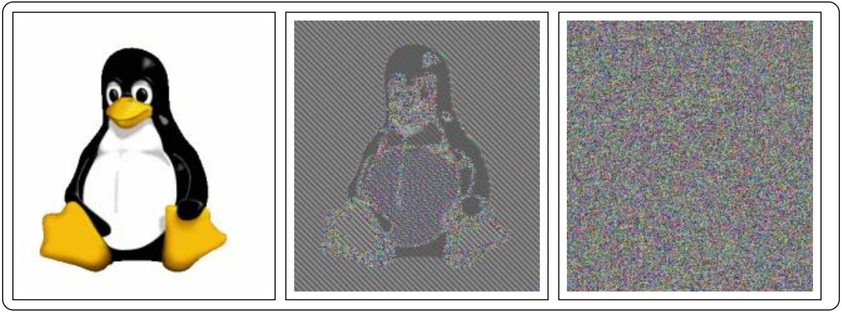

the block size, CFB, OFB, and CTR don't.

- For OFB, CFB, and CTR mode each two messages encrypted with he same key must use a different *IV*.
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An Example for Block Ciphers: AES

History:

- **September 1997:** NIST issued a public call for a new block cipher, supporting a block length of 128 bits and lengths of 128, 192, and 256 bits.
- **August 1998 and March 1999:** AES1 and AES2 conferences organized by NIST.
- **August 1999:** NIST announces 5 finalists:
  - MARS (IBM)
  - RCG (Rivest, Robshaw, Sidney, Yin)
  - Rijndael (Daemen, Rijmen)
  - Serpent (Anderson, Biham, Knudsen)
  - Twofish (Schneier)
- **April 2000:** AES3 conference
- **October 2$^{\text{nd}}$, 2000:** NIST announces that Rijndael has been selected as the proposed AES

An Example for Block Ciphers: AES

Parameters:

- fixed block size of 128bit
- variable key size (in bits): AES-128, AES-192, AES-256

Animation:

`http://www.cs.bc.edu/~straubin/cs381-05/blockciphers/rijndael_ingles2004.swf`

An Example for Block Ciphers: AES

Rijndael S-box:

For y in $GF(2^8) = GF(2)[x]/(x^8 + x^4 + x^3 + x + 1)$ compute

$$\begin{bmatrix} 1 & 0 & 0 & 0 & 1 & 1 & 1 & 1 \\ 1 & 1 & 0 & 0 & 0 & 1 & 1 & 1 \\ 1 & 1 & 1 & 0 & 0 & 0 & 1 & 1 \\ 1 & 1 & 1 & 1 & 0 & 0 & 0 & 1 \\ 1 & 1 & 1 & 1 & 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 1 & 1 & 1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & 1 & 1 & 0 \\ 0 & 0 & 0 & 1 & 1 & 1 & 1 & 1 \end{bmatrix} \begin{bmatrix} x_0 \\ x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \end{bmatrix} + \begin{bmatrix} 1 \\ 1 \\ 0 \\ 0 \\ 0 \\ 1 \\ 1 \\ 0 \end{bmatrix}$$

with $x = y^{-1}$.

An Example for Block Ciphers: AES

Rijndael S-box:

	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
00	63	7c	77	7b	f2	6b	6f	c5	30	01	67	2b	fe	d7	ab	76
10	ca	82	c9	7d	fa	59	47	f0	ad	d4	a2	af	9c	a4	72	c0
20	b7	fd	93	26	36	3f	f7	cc	34	a5	e5	f1	71	d8	31	15
30	04	c7	23	c3	18	96	05	9a	07	12	80	e2	eb	27	b2	75
40	09	83	2c	1a	1b	6e	5a	a0	52	3b	d6	b3	29	e3	2f	84
50	53	d1	00	ed	20	fc	b1	5b	6a	cb	be	39	4a	4c	58	cf
60	d0	ef	aa	fb	43	4d	33	85	45	f9	02	7f	50	3c	9f	a8
70	51	a3	40	8f	92	9d	38	f5	bc	b6	da	21	10	ff	f3	d2
80	cd	0c	13	ec	5f	97	44	17	c4	a7	7e	3d	64	5d	19	73
90	60	81	4f	dc	22	2a	90	88	46	ee	b8	14	de	5e	0b	db
a0	e0	32	3a	0a	49	06	24	5c	c2	d3	ac	62	91	95	e4	79
b0	e7	c8	37	6d	8d	d5	4e	a9	6c	56	f4	ea	65	7a	ae	08
c0	ba	78	25	2e	1c	a6	b4	c6	e8	dd	74	1f	4b	bd	8b	8a
d0	70	3e	b5	66	48	03	f6	0e	61	35	57	b9	86	c1	1d	9e
e0	e1	f8	98	11	69	d9	8e	94	9b	1e	87	e9	ce	55	28	df
f0	8c	a1	89	0d	bf	e6	42	68	41	99	2d	0f	b0	54	bb	16

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Optimizations for 32-bit Architectures:

- Lookup tables $T_0, \ldots, T_3$ combining all steps.

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Security Concerns:

- Theoretical attacks reduce security of AES-128 to $2^{126.1}$.
- Cache-timing attacks are practical attacks but require precise timing measurements.
  $\rightarrow$ AES implementations must be resistant to timing attacks!

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High-Speed Implementations:

- NaCl: `http://nacl.cr.yp.to/features.html`
- `http://cryptojedi.org/crypto/index.shtml#aesbs`

Cryptographic Attack Methods

Plaintext-Based Attacks:

- known plaintext
- chosen plaintext
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Linear Cryptanalysis:

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Linear Cryptanalysis:

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Differential Cryptanalysis:

- chosen plaintext attack
- statistical analysis of the difference of two inputs and the difference of the outputs

Literature

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