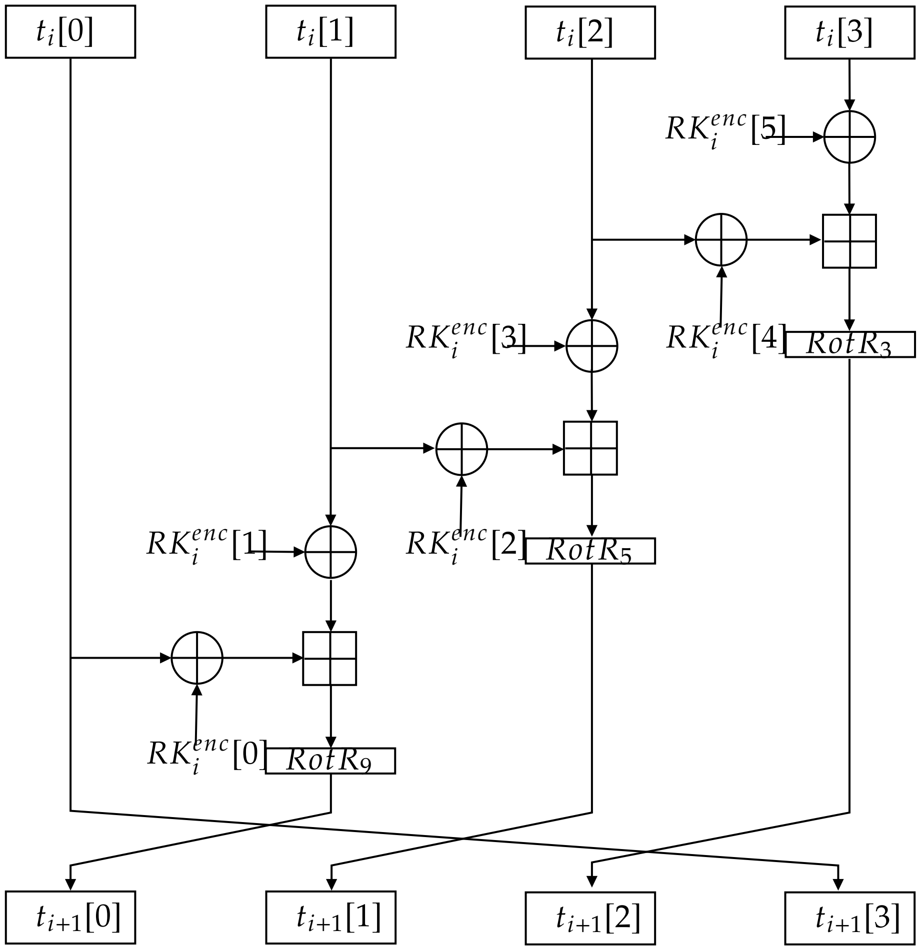
Lightweight Encryption Algorithm
- LEA -

Ji Yong-Hyeon



Department of Information Security, Cryptology, and Mathematics
College of Science and Technology
Kookmin University

January 9, 2024

List of Symbols

Contents

Chapter 1

Block Cipher LEA

1.1 Specification

Table 1.1: Specification Comparison between AES and LEA Block Ciphers

Specification	AES	LEA
Block Size (bits)	128	128
Key Size (bits)	128/192/256	128/192/256
Structure	Substitution-Permutation Network	Generalized Feistel Network
Rounds	10/12/14 (depends on key size)	24/28/32 (depends on key size)
Design Year	1998	2013

Table 1.2: Parameters of the Block Cipher LEA (1-word = 32-bit)

Algorithms	Block Size (N_b-byte)	Key Length (N_k-byte)	Number of Rounds (N_r)	Round-Key Length (byte)	Number of Round-Keys ($N_r + 1$)	Total Size of Round-Keys ($N_b(N_r + 1)$)
LEA-128	16(4-word)	16(4-word)	24	24	11	44 (176-byte)
LEA-192	16(4-word)	24(6-word)	28	24	13	52 (208-byte)
LEA-256	16(4-word)	32(8-word)	32	24	15	60 (240-byte)

1.2 State Representation

Let $\mathsf{state}[0], \mathsf{state}[1], \ldots$ be representation of arrays of bytes. Note that

$$\mathsf{state}[i] := \{input_{8i}, input_{8i+1}, \ldots, input_{8i+7}\} \in \mathbb{F}_{2^8}$$

for $input_i \in \mathbb{F}_2$. For example, $\mathsf{state}[0] = \{input_0, input_1, \ldots, input_7\}$.

The 128-bit plaintext P of LEA is represented as an array of four 32-bit words $P[0], P[1], P[2]$ and $P[3]$. Then

$$P[i] = \mathsf{state}[4i + 3] \parallel \mathsf{state}[4i + 2] \parallel \mathsf{state}[4i + 1] \parallel \mathsf{state}[4i] \quad \text{for} \quad 0 \le i \le 3.$$

Here, $P[i] \in \mathbb{F}_{2^{32=8\cdot 4}}$The key K of LEA is also represented as the same way.

Table 1.3: Representations for words, bytes, and bits

Input Bit Sequence	24	···	31	16	···	23	8	···	15	0	···	7
Word Number	0											
Byte Number	3			2			1			0		
Bit Numbers in Word	31	···										1

Example 1.1.

128-bit Input String	`0x0f1e2d3c4b5a69788796a5b4c3d2e1f0`											
Split into Words	0x0f1e2d3c $P[0]$			0x4b5a6978 $P[1]$			0x8796a5b4 $P[2]$			0xc3d2e1f0 $P[3]$		
$P[0]$ **(Word)**	0x0f1e2d3c											
$P[0]$ **(Bit)**	0b 0000:1111:0001:1110:0010:1101:0011:1010											
Split into Bytes	0x0f state[3]			0x1e state[2]			0x2d state[1]			0x3c state[0]		
state[0] **(Byte)**	0x3c											
Split into Bits	1111:0000			-			-			-		
	24	···	31	16	···	23	8	···	15	0	···	7

```
const char* inputString = "0f1e2d3c4b5a69788796a5b4c3d2e1f0";
u32 key[4];
stringToWordArray(inputString, key);

/*
(gdb) x/32xb key
0x7fffffffd9c0: 0x3c    0x2d    0x1e    0x0f
                0x78    0x69    0x5a    0x4b
0x7fffffffd9c8: 0xb4    0xa5    0x96    0x87
                0xf0    0xe1    0xd2    0xc3
0x7fffffffd9d0: 0x01    0x00    0x00    0x00
                0x00    0x00    0x00    0x00
0x7fffffffd9d8: 0xf6    0x75    0xae    0x03
                0x01    0x00    0x00    0x00
*/
```

1.3 Key Schedule

$$\text{KeySchedule}^{\text{enc}}_{128} : \{0, 1\}^{128=8\cdot 16} \to \{0, 1\}^{4608=192\cdot 24}$$

$$\text{KeySchedule}^{\text{enc}}_{192} : \{0, 1\}^{192=8\cdot 24} \to \{0, 1\}^{5376=192\cdot 28}$$

$$\text{KeySchedule}^{\text{enc}}_{256} : \{0, 1\}^{256=8\cdot 32} \to \{0, 1\}^{6144=192\cdot 24}$$

1.3.1 Round Constant

The constant $\delta[i] \in \mathbb{F}_{2^{32}}$ ($i \in \{1, ..., 7\}$) is as follows:

i	$\delta[i]$	value
0	$\delta[0]$	`0xc3efe9db`
1	$\delta[1]$	`0x44626b02`
2	$\delta[2]$	`0x79e27c8a`
3	$\delta[3]$	`0x78df30ec`
4	$\delta[4]$	`0x715ea49e`
5	$\delta[5]$	`0xc785da0a`
6	$\delta[6]$	`0xe04ef22a`
7	$\delta[7]$	`0xe5c40957`

1.3.2 Rotation Function

Algorithm 1: Rotation to Left and Right

/* RotL : $\{0,1\}^{32} \times \{0,1\}^{32} \to \{0,1\}^{32}$ */

Function RotL(value, shift):

  return (value $\ll$ shift) | (value $\gg$ (32 − shift));

end

/* RotR : $\{0,1\}^{32} \times \{0,1\}^{32} \to \{0,1\}^{32}$ */

Function RotR(value, shift):

  return (value $\gg$ shift) | (value $\ll$ (32 − shift));

end

1.3.3 Encryption Key Schedule of LEA-128

Algorithm 2: Encryption Key Schedule (LEA-128)

Input: User-key $\mathsf{UK} = \mathsf{UK}[0] \parallel \mathsf{UK}[1] \parallel \mathsf{UK}[2] \parallel \mathsf{UK}[3]$ ($\mathsf{UK}[i] \in \{0,1\}^{32}$)

Output: Encryption Round-keys $\{\mathsf{RK}_i^{\mathsf{enc}}\}_{i=0}^{23}$ ($\mathsf{RK}_i^{\mathsf{enc}} \in \{0,1\}^{192}$)

/* $\mathsf{UK} \in \{0,1\}^{128}$ is 16-byte and $\left\{\mathsf{RK}_i^{\mathsf{enc}}\right\}_{i=0}^{23} \in \{0,1\}^{4608}$ is 576-byte */

for $i = 0$ **to** 3 **do**

  $T[i] = \mathsf{UK}[i]$ // $T = T[0] \parallel \cdots \parallel T[3] \in \{0,1\}^{128=32*4}$

end

for $i = 0$ **to** 23 **do**

  $T[0] \leftarrow \mathtt{RotL}(T[0] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i+0), 1)$ // $T[i] \in \{0,1\}^{32}$

  $T[1] \leftarrow \mathtt{RotL}(T[1] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i+1), 3)$

  $T[2] \leftarrow \mathtt{RotL}(T[2] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i+2), 6)$

  $T[3] \leftarrow \mathtt{RotL}(T[3] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i+3), 11)$

  $\mathsf{RK}_i^{\mathsf{enc}} \leftarrow T[0] \parallel T[1] \parallel T[2] \parallel T[1] \parallel T[3] \parallel T[1]$ // $\mathsf{RK}_i^{\mathsf{enc}} \in \{0,1\}^{196=32*6}$

end

return $\left\{\mathsf{RK}_i^{\mathsf{enc}}\right\}_{i=0}^{23}$

1.4 Encryption of LEA-128

Algorithm 3: Encryption of LEA-128

Input: block $\mathsf{src} \in \{0, 1\}^{128=8*16}$, encryption round-keys $\{\mathsf{RK}_i^{\mathsf{enc}}\}_{i=0}^{N_r-1=23}$

Output: block $\mathsf{dst} \in \{0, 1\}^{128=8*16}$

$t_0 \leftarrow \mathsf{src}$

for $i = 0$ **to** $N_r - 1$ **do**

  $t_{i+1}[0] \leftarrow \mathtt{RotR}(\,t_i[0] \oplus \mathsf{RK}_i^{\mathsf{enc}}[0] \boxplus (t_i[1] \oplus \mathsf{RK}_i^{\mathsf{enc}}[1])\,, 9)$

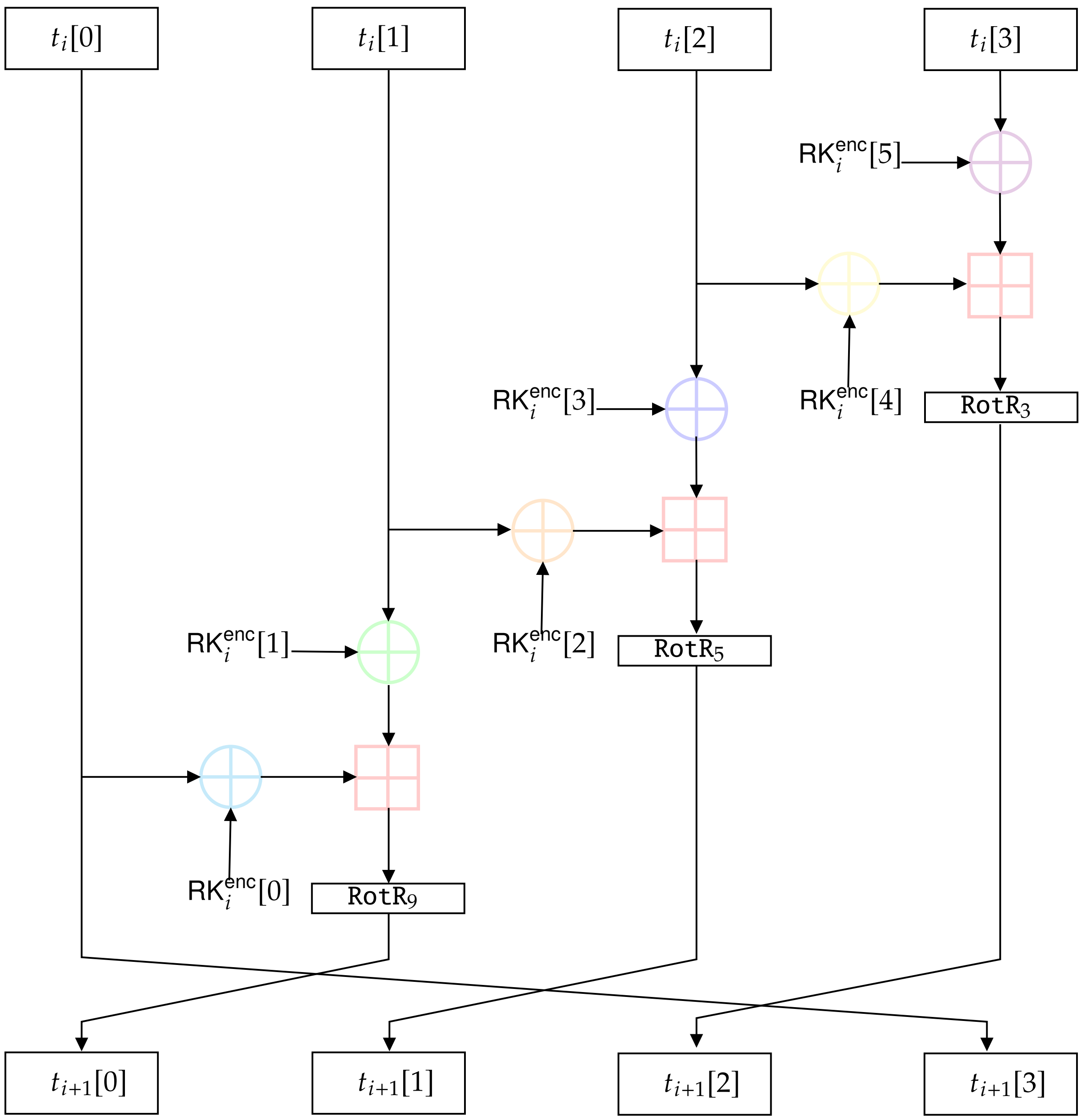
  $t_{i+1}[1] \leftarrow \mathtt{RotR}(\,t_i[1] \oplus \mathsf{RK}_i^{\mathsf{enc}}[2] \boxplus (t_i[2] \oplus \mathsf{RK}_i^{\mathsf{enc}}[3])\,, 5)$

  $t_{i+1}[2] \leftarrow \mathtt{RotR}(\,t_i[2] \oplus \mathsf{RK}_i^{\mathsf{enc}}[4] \boxplus (t_i[3] \oplus \mathsf{RK}_i^{\mathsf{enc}}[5])\,, 3)$

  $t_{i+1}[3] \leftarrow t_i[0]$

end

return $\mathsf{dst} \leftarrow t_{N_r}$



1.5 Decryption Key Schedule of LEA-128

Algorithm 4: Decryption Key Schedule (LEA-128)

Input: User-key $\mathsf{UK} = (\mathsf{UK}_0, \ldots, \mathsf{UK}_{15})$ ($\mathsf{UK}_i \in \{0, 1\}^8$) // $\mathsf{UK} \in \{0, 1\}^{128}$ is 16-byte

Output: Decryption Round-keys $\{\mathsf{RK}_i^{\mathsf{dec}}\}_{i=0}^{23}$ ($\mathsf{RK}_i^{\mathsf{dec}} \in \{0, 1\}^{192}$)

/* $\{\mathsf{RK}_i^{\mathsf{enc}}\}_{i=0}^{23} \in \{0, 1\}^{4608}$ is 576-byte */

$T \leftarrow \mathsf{UK}$ // $T \in \{0, 1\}^{128}$

for $i = 0$ **to** 23 **do**

  $T[0] \leftarrow \mathtt{RotL}(T[0] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i + 0), 1)$ // $T[i] \in \{0, 1\}^{32}$

  $T[1] \leftarrow \mathtt{RotL}(T[1] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i + 1), 3)$

  $T[2] \leftarrow \mathtt{RotL}(T[2] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i + 2), 6)$

  $T[3] \leftarrow \mathtt{RotL}(T[3] \boxplus \mathtt{RotL}(\delta[i \bmod 4], i + 3), 11)$

  $\mathsf{RK}_i^{\mathsf{dec}} \leftarrow T[1] \parallel T[3] \parallel T[1] \parallel T[2] \parallel T[1] \parallel T[0]$ // $\mathsf{RK}_i^{\mathsf{dec}} \in \{0, 1\}^{196=32*6}$

end

return $\left\{\mathsf{RK}_i^{\mathsf{dec}}\right\}_{i=0}^{23}$

1.6 Decryption of LEA-128

Algorithm 5: Decryption of LEA-128

Input: block src $\in \{0, 1\}^{128=8*16}$, decryption round-keys $\{\mathsf{RK}_i^{\mathsf{dec}}\}_{i=0}^{N_r-1=23}$

Output: block dst $\in \{0, 1\}^{128=8*16}$

$t_0 \leftarrow \mathsf{src}$

for $i = 0$ **to** $N_r - 1$ **do**

  $t_{i+1}[0] \leftarrow t_i[3]$

  $t_{i+1}[1] \leftarrow (\mathtt{RotR}(t_i[0], 9) \boxminus (t_{i+1}[0] \oplus \mathsf{RK}_i^{\mathsf{dec}}[0])) \oplus \mathsf{RK}_i^{\mathsf{dec}}[1]$

  $t_{i+1}[2] \leftarrow (\mathtt{RotR}(t_i[1], 9) \boxminus (t_{i+1}[1] \oplus \mathsf{RK}_i^{\mathsf{dec}}[2])) \oplus \mathsf{RK}_i^{\mathsf{dec}}[3]$

  $t_{i+1}[3] \leftarrow (\mathtt{RotR}(t_i[2], 9) \boxminus (t_{i+1}[2] \oplus \mathsf{RK}_i^{\mathsf{dec}}[4])) \oplus \mathsf{RK}_i^{\mathsf{dec}}[5]$

end

return dst $\leftarrow t_{N_r}$

Appendix A

Additional Data A

A.1 Substitution-BOX