Related-Key Kasumi attacks

Ján Kotrady

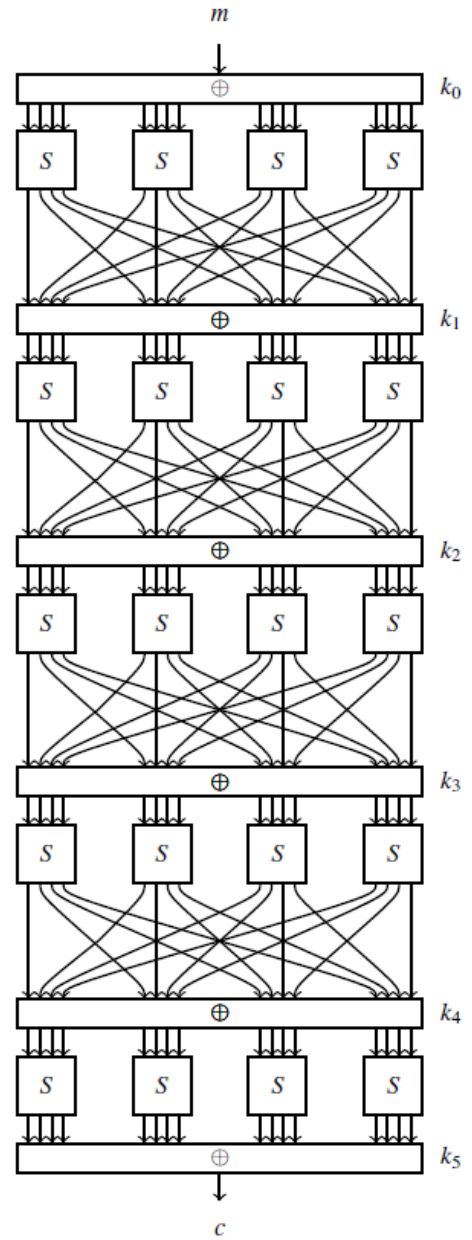
Obsah

- Diferenčná kryptoanalýza
- Boomerang attack*
- Amplified Boomerang Attack*
- Related-Key Attack*
- Related-Key Boomerang Attack*
- Related-Key Rectangle Attack*
- KASUMI Related-Key Rectangle Attack
- KASUMI Related-Key Sandwich (Boomerang) Attack*

Diferenčná kryptoanalýza „myšlienka“

Blokové šifry

- Najúčinnejšia kryptoanalýza (¬DES)
- Základ: „rundy“, Feistelová sieť
- **CPA – Choosen plain-text attack**
- Ciele:
  - „Zbaviť sa kľúča“
  - Zistit kľúč
  - Útok hrubou silou jednoduchší



XOR – základný princíp

- $\oplus$
- XOR šifra: k_1 kľúč, $e_{k_1}(m) = m \oplus k_1$, $d_{k_1}(m) = m \oplus k_1$
- $d_{k_1}\left(e_{k_1}(m)\right) = m \oplus k_1 \oplus k_1$

XOR operácie			
1	$\oplus$	1	0
1	$\oplus$	0	1
0	$\oplus$	1	1
0	$\oplus$	0	0

k_1=101101			
1	$\oplus$	1	0
0	$\oplus$	0	0
1	$\oplus$	1	0
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0	$\oplus$	0	0
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- $(m_1 \oplus k_1) \oplus (m_2 \oplus k_2)$

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Práve sme pochopili diferenčnú kryptoanalýzu

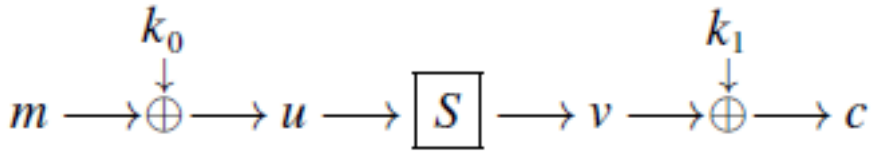
Práve sme pochopili diferenčnú kryptoanalýzu nasleduje jej aplikácia ☹

CipherOne

CipherOne

$$c = S[m \oplus k_0] \oplus k_1$$

x	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
$S[x]$	6	4	c	5	0	7	2	e	1	f	3	d	8	a	9	b



CIPHERONE$(m_0, k_0 \| k_1)$	CIPHERONE$(m_1, k_0 \| k_1)$
$u_0 = m_0 \oplus k_0$	$u_1 = m_1 \oplus k_0$
$v_0 = S[u_0]$	$v_1 = S[u_1]$
$c_0 = v_0 \oplus k_1$	$c_1 = v_1 \oplus k_1$

Aplikácia v praxi

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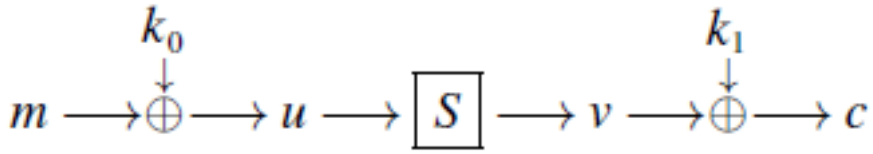

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Aplikácia v praxi

- $m_0 \oplus m_1 = (m_0 \oplus k_0) \oplus (m_1 \oplus k_0) = u_0 \oplus u_1$
- (m_0, c_0), (m_1, c_1) - pár

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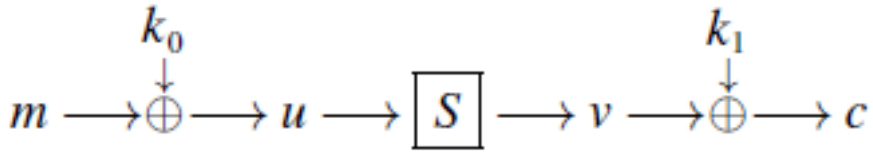

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- $(m_0, c_0), (m_1, c_1)$ - pár
- $u_0 \oplus u_1 = S^{-1}[t \oplus c_0] \oplus S^{-1}[t \oplus c_1], \forall t$

CipherTwo

CipherTwo

$$c = S[S[m \oplus k_0] \oplus k_1] \oplus k_2$$

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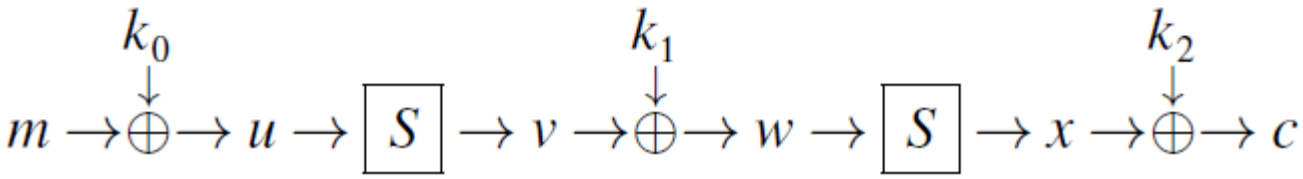

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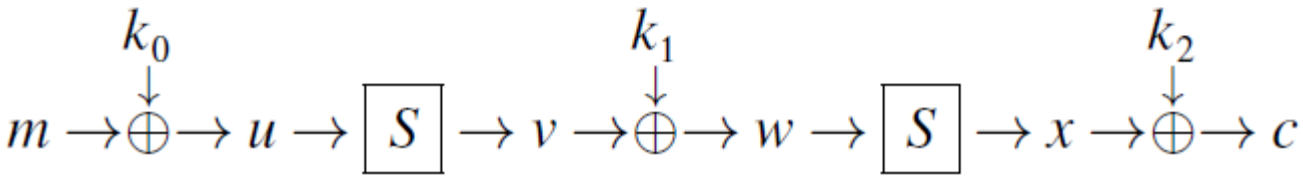

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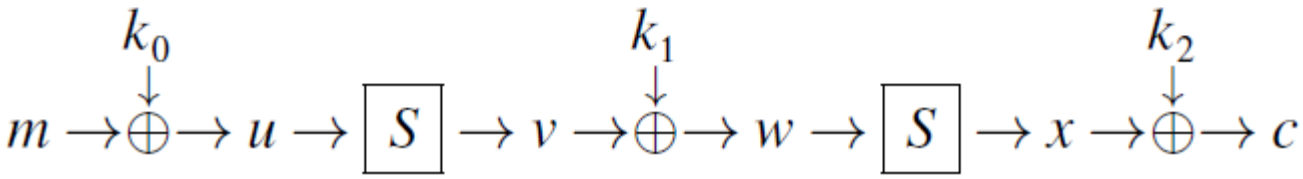

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- Nevieme overiť tip t

Inputs and output relations for i and $j = i \oplus \mathtt{f}$ across $S[\cdot]$.

i	j	$S[i]$	$S[j]$	$S[i] \oplus S[j]$
0	f	6	b	d
1	e	4	9	d
2	d	c	a	6
3	c	5	8	d
4	b	0	d	d
5	a	7	3	4
6	9	2	f	d
7	8	e	1	f
8	7	1	e	f
9	6	f	2	d
a	5	3	7	4
b	4	d	0	d
c	3	8	5	d
d	2	a	c	6
e	1	9	4	d
f	0	b	6	d

Analýza S-boxu S[x]=f

- j⊕i = f, j= i⊕ f
- **d** = 10/16

CipherTwo

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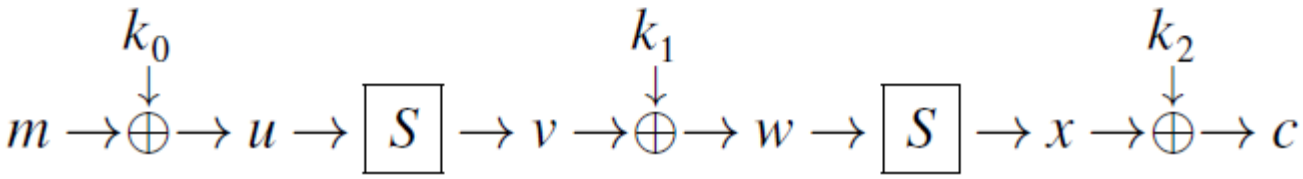

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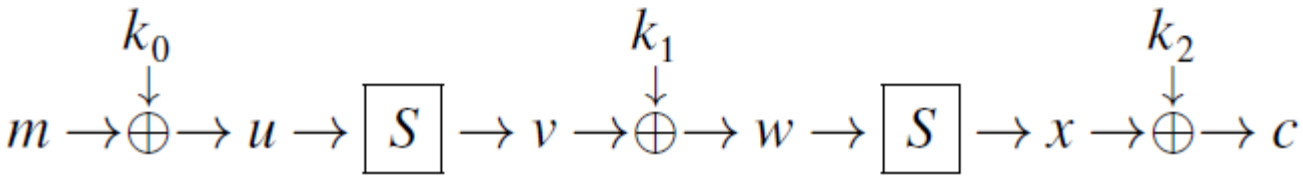

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- Nevieme overiť tip t
- $m_0 = \mathrm{f} \oplus m_1$

CipherTwo

$$c = S[S[m \oplus k_0] \oplus k_1] \oplus k_2$$

x	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
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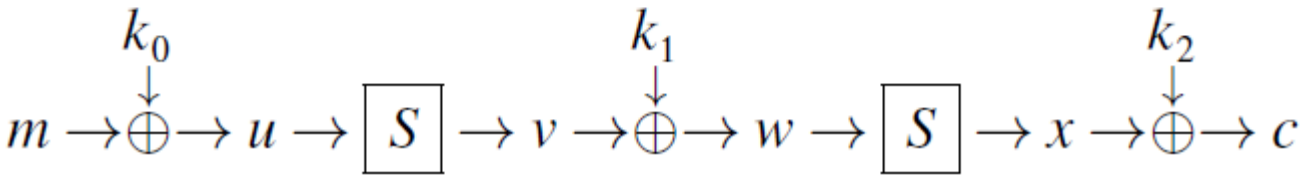

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- Nevieme overiť tip t
- $m_0 = \mathbf{f} \oplus m_1$
- $P\{S[u_0] \oplus S[u_1] = \mathbf{d}\} = \frac{10}{16}$

CipherTwo

$$c = S[S[m \oplus k_0] \oplus k_1] \oplus k_2$$

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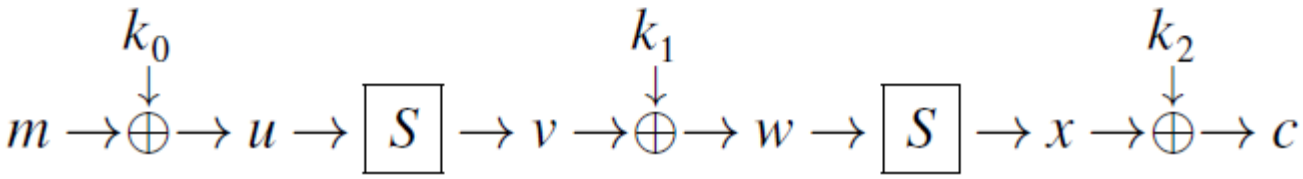

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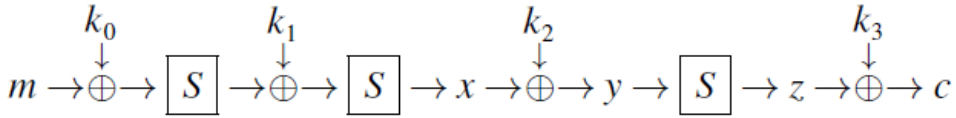
- $m_0 = \mathbf{f} \oplus m_1$
- $P\{S[u_0] \oplus S[u_1] = \mathbf{d}\} = \frac{10}{16}$
- Counter $T_1, \ldots, T_{|k|}$

CipherThree

CipherThree

$$c = S[S[S[m \oplus k_0] \oplus k_1] \oplus k_2] \oplus k_3$$

x	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
$S[x]$	6	4	c	5	0	7	2	e	1	f	3	d	8	a	9	b



Δout

Δ in

	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
0	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	6	-	-	-	-	2	-	2	-	-	2	-	4	-
2	-	6	6	-	-	-	-	-	-	2	2	-	-	-	-	-
3	-	-	-	6	-	2	-	-	2	-	-	-	4	-	2	-
4	-	-	-	2	-	2	4	-	-	2	2	2	-	-	2	-
5	-	2	2	-	4	-	-	4	2	-	-	2	-	-	-	-
6	-	-	2	-	4	-	-	2	2	-	2	2	2	-	-	-
7	-	-	-	-	-	4	4	-	2	2	2	2	-	-	-	-
8	-	-	-	-	-	2	-	2	4	-	-	4	-	2	-	2
9	-	2	-	-	-	2	2	2	-	4	2	-	-	-	-	2
a	-	-	-	-	2	2	-	-	-	4	4	-	2	2	-	-
b	-	-	-	2	2	-	2	2	2	-	-	4	-	-	2	-
c	-	4	-	2	-	2	-	-	2	-	-	-	-	-	6	-
d	-	-	-	-	-	-	2	2	-	-	-	-	6	2	-	4
e	-	2	-	4	2	-	-	-	-	-	2	-	-	-	-	6
f	-	-	-	-	2	-	2	-	-	-	-	-	-	10	-	2

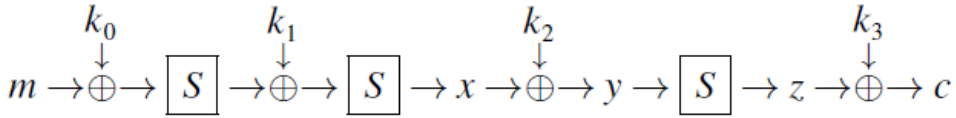
Diferenčná tabuľka S-box charakteristika

- (α,β), $\alpha \rightarrow \beta$

CipherThree

$$c = S[S[S[m \oplus k_0] \oplus k_1] \oplus k_2] \oplus k_3$$

x	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
$S[x]$	6	4	c	5	0	7	2	e	1	f	3	d	8	a	9	b



Δ in

Δout

	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
0	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	6	-	-	-	-	2	-	2	-	-	2	-	4	-
2	-	6	6	-	-	-	-	-	-	2	2	-	-	-	-	-
3	-	-	-	6	-	2	-	-	2	-	-	-	4	-	2	-
4	-	-	-	2	-	2	4	-	-	2	2	2	-	-	2	-
5	-	2	2	-	4	-	-	4	2	-	-	2	-	-	-	-
6	-	-	2	-	4	-	-	2	2	-	2	2	2	-	-	-
7	-	-	-	-	-	4	4	-	2	2	2	2	-	-	-	-
8	-	-	-	-	-	2	-	2	4	-	-	4	-	2	-	2
9	-	2	-	-	-	2	2	2	-	4	2	-	-	-	-	2
a	-	-	-	-	2	2	-	-	-	4	4	-	2	2	-	-
b	-	-	-	2	2	-	2	2	2	-	-	4	-	-	2	-
c	-	4	-	2	-	2	-	-	2	-	-	-	-	-	6	-
d	-	-	-	-	-	-	2	2	-	-	-	-	6	2	-	4
e	-	2	-	4	2	-	-	-	-	-	2	-	-	-	-	6
f	-	-	-	-	2	-	2	-	-	-	-	-	-	10	-	2

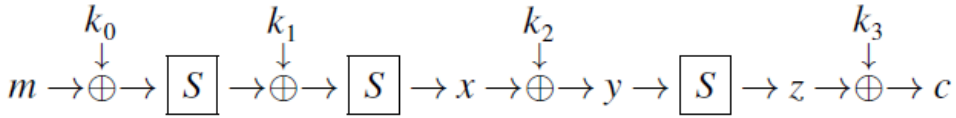
Diferenčná tabuľka S-box charakteristika

- (α,β), $\alpha \rightarrow \beta$
- $P_1\{S[u_0] \oplus S[u_1] = \mathbf{d}\} = \frac{10}{16}$

CipherThree

$$c = S[S[S[m \oplus k_0] \oplus k_1] \oplus k_2] \oplus k_3$$

x	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
$S[x]$	6	4	c	5	0	7	2	e	1	f	3	d	8	a	9	b



Δout

Δ in

	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
0	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	6	-	-	-	-	2	-	2	-	-	2	-	4	-
2	-	6	6	-	-	-	-	-	-	2	2	-	-	-	-	-
3	-	-	-	6	-	2	-	-	2	-	-	-	4	-	2	-
4	-	-	-	2	-	2	4	-	-	2	2	2	-	-	2	-
5	-	2	2	-	4	-	-	4	2	-	-	2	-	-	-	-
6	-	-	2	-	4	-	-	2	2	-	2	2	2	-	-	-
7	-	-	-	-	-	4	4	-	2	2	2	2	-	-	-	-
8	-	-	-	-	-	2	-	2	4	-	-	4	-	2	-	2
9	-	2	-	-	-	2	2	2	-	4	2	-	-	-	-	2
a	-	-	-	-	2	2	-	-	-	4	4	-	2	2	-	-
b	-	-	-	2	2	-	2	2	2	-	-	4	-	-	2	-
c	-	4	-	2	-	2	-	-	2	-	-	-	-	-	6	-
d	-	-	-	-	-	-	2	2	-	-	-	-	6	2	-	4
e	-	2	-	4	2	-	-	-	-	-	2	-	-	-	-	6
f	-	-	-	-	2	-	2	-	-	-	-	-	-	10	-	2

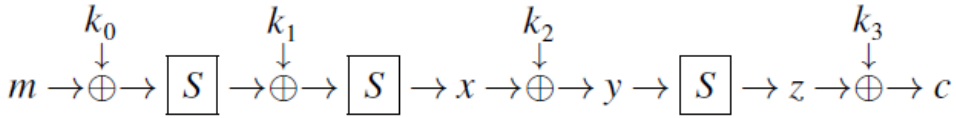
Diferenčná tabuľka S-box charakteristika

- (α,β), $\alpha \rightarrow \beta$
- $P_1\{S[u_0] \oplus S[u_1] = \mathbf{d}\} = \frac{10}{16}$
- $P_2\{S[\mathbf{d}] = \mathbf{c}\} = \frac{6}{16}$

CipherThree

$$c = S[S[S[m \oplus k_0] \oplus k_1] \oplus k_2] \oplus k_3$$

x	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
$S[x]$	6	4	c	5	0	7	2	e	1	f	3	d	8	a	9	b



Δ in / Δout

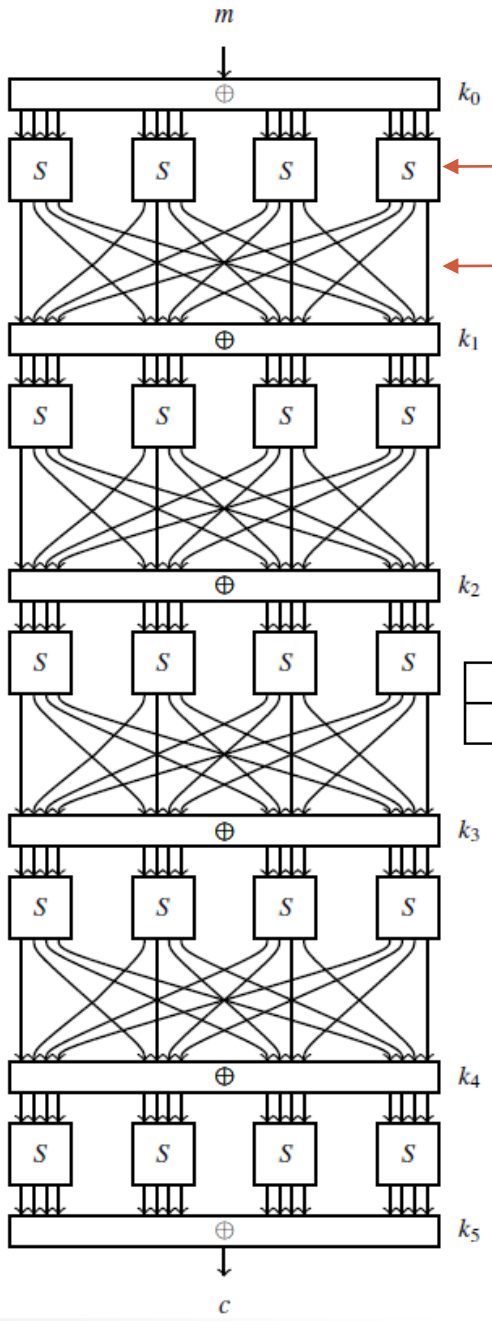
	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
0	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	6	-	-	-	-	2	-	2	-	-	2	-	4	-
2	-	6	6	-	-	-	-	-	-	2	2	-	-	-	-	-
3	-	-	-	6	-	2	-	-	2	-	-	-	4	-	2	-
4	-	-	-	2	-	2	4	-	-	2	2	2	-	-	2	-
5	-	2	2	-	4	-	-	4	2	-	-	2	-	-	-	-
6	-	-	2	-	4	-	-	2	2	-	2	2	2	-	-	-
7	-	-	-	-	-	4	4	-	2	2	2	2	-	-	-	-
8	-	-	-	-	-	2	-	2	4	-	-	4	-	2	-	2
9	-	2	-	-	-	2	2	2	-	4	2	-	-	-	-	2
a	-	-	-	-	2	2	-	-	-	4	4	-	2	2	-	-
b	-	-	-	2	2	-	2	2	2	-	-	4	-	-	2	-
c	-	4	-	2	-	2	-	-	2	-	-	-	-	-	6	-
d	-	-	-	-	-	-	2	2	-	-	-	-	6	2	-	4
e	-	2	-	4	2	-	-	-	-	-	2	-	-	-	-	6
f	-	-	-	-	2	-	2	-	-	-	-	-	-	10	-	2

Diferenčná tabuľka S-box charakteristika

- (α,β), $\alpha \rightarrow \beta$
- $P_1\{S[u_0] \oplus S[u_1] = \mathbf{d}\} = \frac{10}{16}$
- $P_2\{S[\mathbf{d}] = \mathbf{c}\} = \frac{6}{16}$
- $P_1 \,\&\, P_2 = \frac{10}{16}\frac{6}{16}$

CipherFour

CipherFour



S-box

P-box

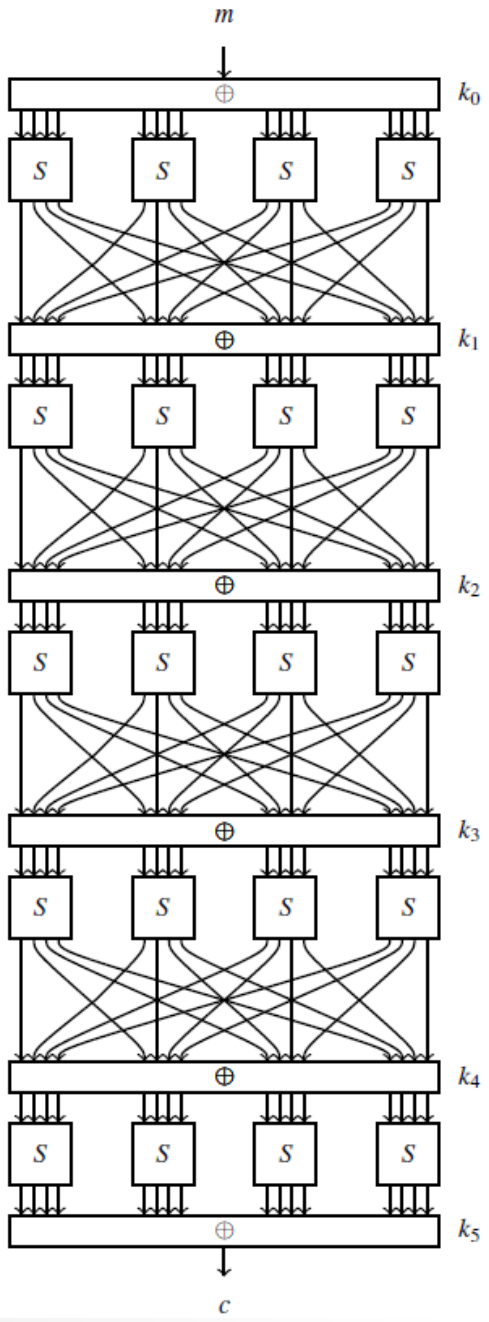
x	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
$S[x]$	6	4	c	5	0	7	2	e	1	f	3	d	8	a	9	b

i	0	1	2	3	4	5	6	7
$P[i]$	0	4	8	12	1	5	9	13
i	8	9	10	11	12	13	14	15
$P[i]$	2	6	10	14	3	7	11	15

Spájanie charakteristík

- S-box – nelineárne
- P-box – permutácia

CipherFour



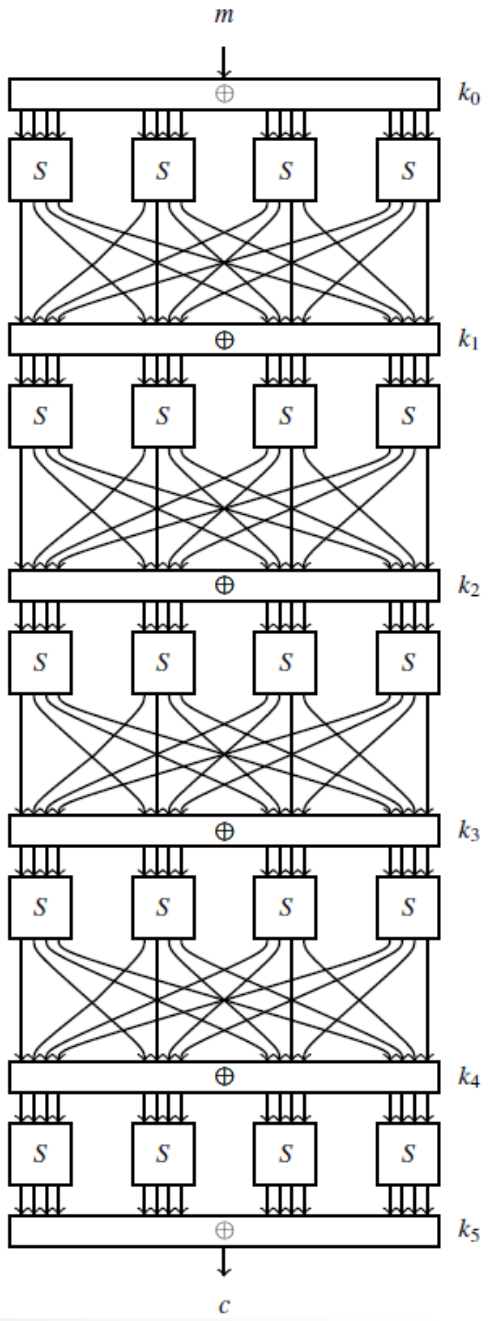
Δout

Δ in	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
0	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	6	-	-	-	-	2	-	2	-	-	2	-	4	-
2	-	6	6	-	-	-	-	-	-	2	2	-	-	-	-	-
3	-	-	-	6	-	2	-	-	2	-	-	-	4	-	2	-
4	-	-	-	2	-	2	4	-	-	2	2	2	-	-	2	-
5	-	2	2	-	4	-	-	4	2	-	-	2	-	-	-	-
6	-	-	2	-	4	-	-	2	2	-	2	2	2	-	-	-
7	-	-	-	-	-	4	4	-	2	2	2	2	-	-	-	-
8	-	-	-	-	-	2	-	2	4	-	-	4	-	2	-	2
9	-	2	-	-	-	2	2	2	-	4	2	-	-	-	-	2
a	-	-	-	-	2	2	-	-	-	4	4	-	2	2	-	-
b	-	-	-	2	2	-	2	2	2	-	-	4	-	-	2	-
c	-	4	-	2	-	2	-	-	2	-	-	-	-	-	6	-
d	-	-	-	-	-	-	2	2	-	-	-	-	6	2	-	4
e	-	2	-	4	2	-	-	-	-	-	2	-	-	-	-	6
f	-	-	-	-	2	-	2	-	-	-	-	-	-	10	-	2

Spájanie charakteristík

- $(\alpha_1,\alpha_2,\alpha_3,\alpha_4) \xrightarrow{S} (\beta_1,\beta_2,\beta_3,\beta_4)$
- $(\beta_1,\beta_2,\beta_3,\beta_4) \xrightarrow{P} (\gamma_1,\gamma_2,\gamma_3,\gamma_4)$
- $(\alpha_1,\alpha_2,\alpha_3,\alpha_4) \xrightarrow{R} (\gamma_1,\gamma_2,\gamma_3,\gamma_4)$

CipherFour



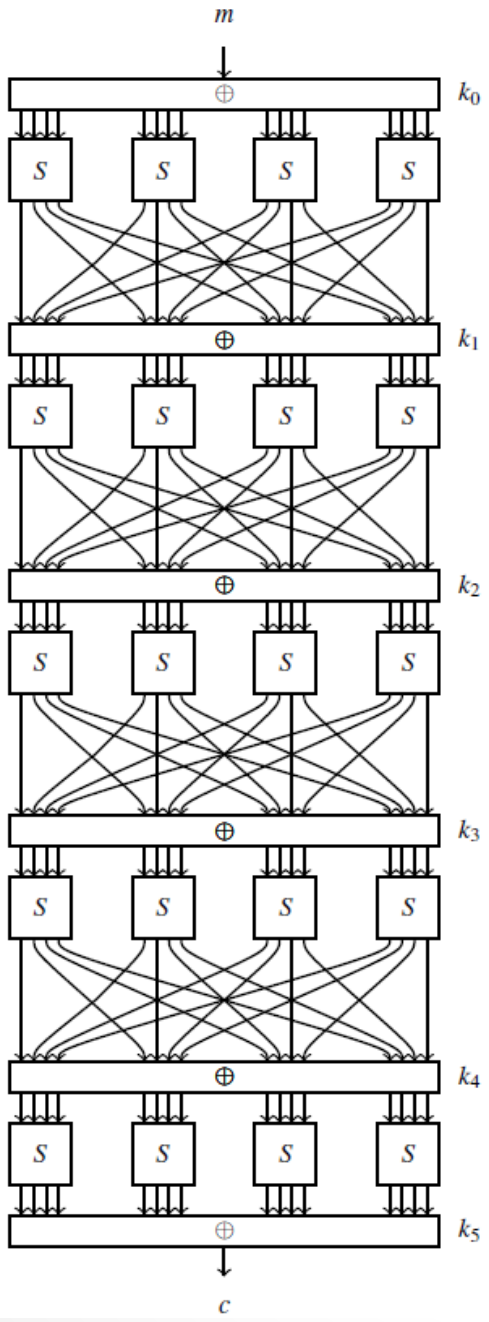
Δ in \ Δout

	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
0	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	6	-	-	-	-	2	-	2	-	-	2	-	4	-
2	-	6	6	-	-	-	-	-	-	2	2	-	-	-	-	-
3	-	-	-	6	-	2	-	-	2	-	-	-	4	-	2	-
4	-	-	-	2	-	2	4	-	-	2	2	2	-	-	2	-
5	-	2	2	-	4	-	-	4	2	-	-	2	-	-	-	-
6	-	-	2	-	4	-	-	2	2	-	2	2	2	-	-	-
7	-	-	-	-	-	4	4	-	2	2	2	2	-	-	-	-
8	-	-	-	-	-	2	-	2	4	-	-	4	-	2	-	2
9	-	2	-	-	-	2	2	2	-	4	2	-	-	-	-	2
a	-	-	-	-	2	2	-	-	-	4	4	-	2	2	-	-
b	-	-	-	2	2	-	2	2	2	-	-	4	-	-	2	-
c	-	4	-	2	-	2	-	-	2	-	-	-	-	-	6	-
d	-	-	-	-	-	-	2	2	-	-	-	-	6	2	-	4
e	-	2	-	4	2	-	-	-	-	-	2	-	-	-	-	6
f	-	-	-	-	2	-	2	-	-	-	-	-	-	10	-	2

Spájanie charakteristík

- $(0,0,0,\mathrm{f}) \xrightarrow{S} (0,0,0,\mathrm{d})$
- $(0,0,0,\mathrm{d}) \xrightarrow{P} (1,1,0,1)$
- $P_1 = \frac{10}{16}$

CipherFour



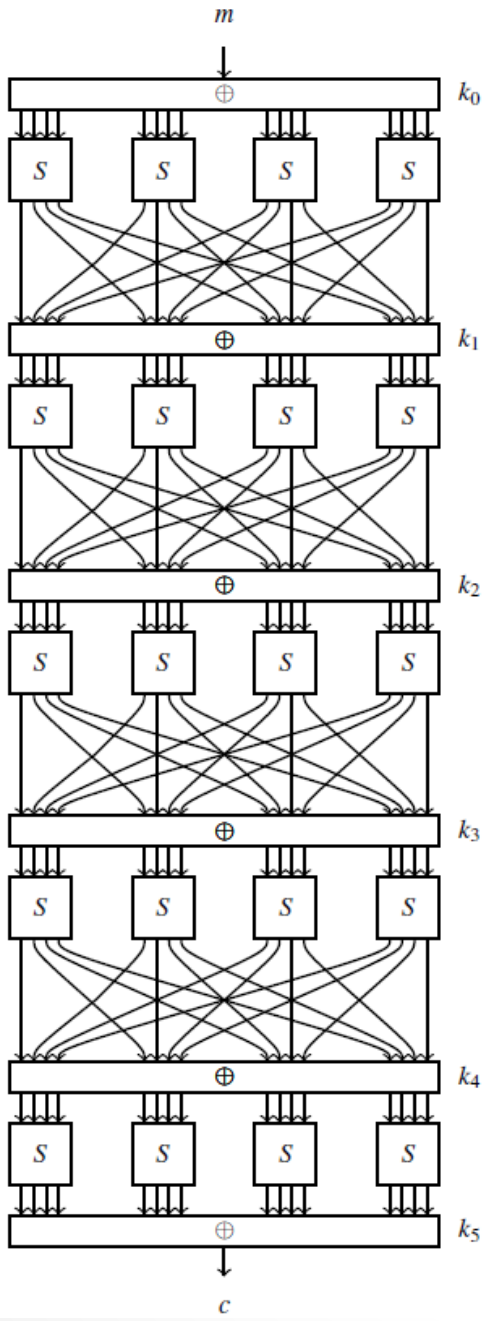
Δ in \ Δout

	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
0	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	6	-	-	-	-	2	-	2	-	-	2	-	4	-
2	-	6	6	-	-	-	-	-	-	2	2	-	-	-	-	-
3	-	-	-	6	-	2	-	-	2	-	-	-	4	-	2	-
4	-	-	-	2	-	2	4	-	-	2	2	2	-	-	2	-
5	-	2	2	-	4	-	-	4	2	-	-	2	-	-	-	-
6	-	-	2	-	4	-	-	2	2	-	2	2	2	-	-	-
7	-	-	-	-	-	4	4	-	2	2	2	2	-	-	-	-
8	-	-	-	-	-	2	-	2	4	-	-	4	-	2	-	2
9	-	2	-	-	-	2	2	2	-	4	2	-	-	-	-	2
a	-	-	-	-	2	2	-	-	-	4	4	-	2	2	-	-
b	-	-	-	2	2	-	2	2	2	-	-	4	-	-	2	-
c	-	4	-	2	-	2	-	-	2	-	-	-	-	-	6	-
d	-	-	-	-	-	-	2	2	-	-	-	-	6	2	-	4
e	-	2	-	4	2	-	-	-	-	-	2	-	-	-	-	6
f	-	-	-	-	2	-	2	-	-	-	-	-	10	-	2	

Spájanie charakteristík

- $(0,0,0,\mathrm{f}) \xrightarrow{S} (0,0,0,\mathrm{d})$
- $(0,0,0,\mathrm{d}) \xrightarrow{P} (1,1,0,1)$
- $P_1 = \frac{10}{16}$
- $(1,1,0,1) \xrightarrow{S} (2,2,0,2)$
- $(2,2,0,2) \xrightarrow{P} (0,0,\mathrm{d},0)$
- $P_2 = (\frac{6}{16})^3$
- $P_1 \ \& \ P_2 = \frac{10}{16}(\frac{6}{16})^3 = \frac{135}{4096}$

CipherFour



Δout

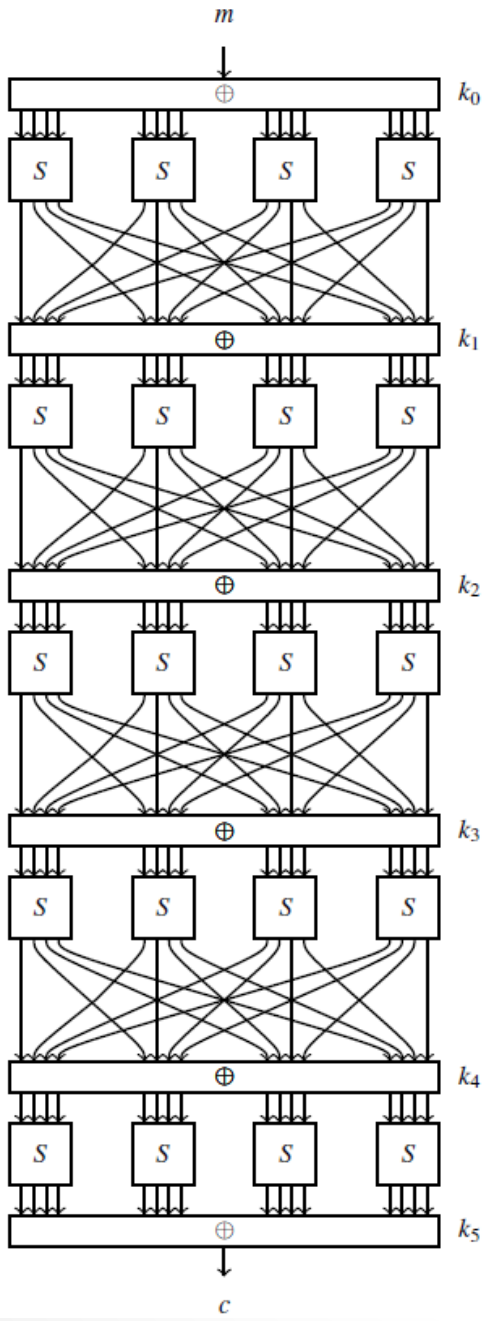
Δ in

	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
0	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	6	-	-	-	-	2	-	2	-	-	2	-	4	-
2	-	6	6	-	-	-	-	-	-	2	2	-	-	-	-	-
3	-	-	-	6	-	2	-	-	2	-	-	-	4	-	2	-
4	-	-	-	2	-	2	4	-	-	2	2	2	-	-	2	-
5	-	2	2	-	4	-	-	4	2	-	-	2	-	-	-	-
6	-	-	2	-	4	-	-	2	2	-	2	2	2	-	-	-
7	-	-	-	-	-	4	4	-	2	2	2	2	-	-	-	-
8	-	-	-	-	-	2	-	2	4	-	-	4	-	2	-	2
9	-	2	-	-	-	2	2	2	-	4	2	-	-	-	-	2
a	-	-	-	-	2	2	-	-	-	4	4	-	2	2	-	-
b	-	-	-	2	2	-	2	2	2	-	-	4	-	-	2	-
c	-	4	-	2	-	2	-	-	2	-	-	-	-	-	6	-
d	-	-	-	-	-	-	2	2	-	-	-	-	6	2	-	4
e	-	2	-	4	2	-	-	-	-	-	2	-	-	-	-	6
f	-	-	-	-	2	-	2	-	-	-	-	-	-	10	-	2

Spájanie charakteristík

- $(0,0,2,0) \xrightarrow{S} (0,0,2,0)$
- $(0,0,2,0) \xrightarrow{P} (0,0,2,0)$
- $P_1 = \frac{6}{16}$
- $(0,0,2,0) \xrightarrow{S} (0,0,2,0)$
- $(0,0,2,0) \xrightarrow{P} (0,0,2,0)$
- $P_2 = \frac{6}{16}$
- $P_1 \ \& \ P_2 = (\frac{6}{16})^2$

CipherFour



Δ in \ Δout

	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
0	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	6	-	-	-	-	2	-	2	-	-	2	-	4	-
2	-	6	6	-	-	-	-	-	-	2	2	-	-	-	-	-
3	-	-	-	6	-	2	-	-	2	-	-	-	4	-	2	-
4	-	-	-	2	-	2	4	-	-	2	2	2	-	-	2	-
5	-	2	2	-	4	-	-	4	2	-	-	2	-	-	-	-
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9	-	2	-	-	-	2	2	2	-	4	2	-	-	-	-	2
a	-	-	-	-	2	2	-	-	-	4	4	-	2	2	-	-
b	-	-	-	2	2	-	2	2	2	-	-	4	-	-	2	-
c	-	4	-	2	-	2	-	-	2	-	-	-	-	-	6	-
d	-	-	-	-	-	-	2	2	-	-	-	-	6	2	-	4
e	-	2	-	4	2	-	-	-	-	-	2	-	-	-	-	6
f	-	-	-	-	2	-	2	-	-	-	-	-	-	10	-	2

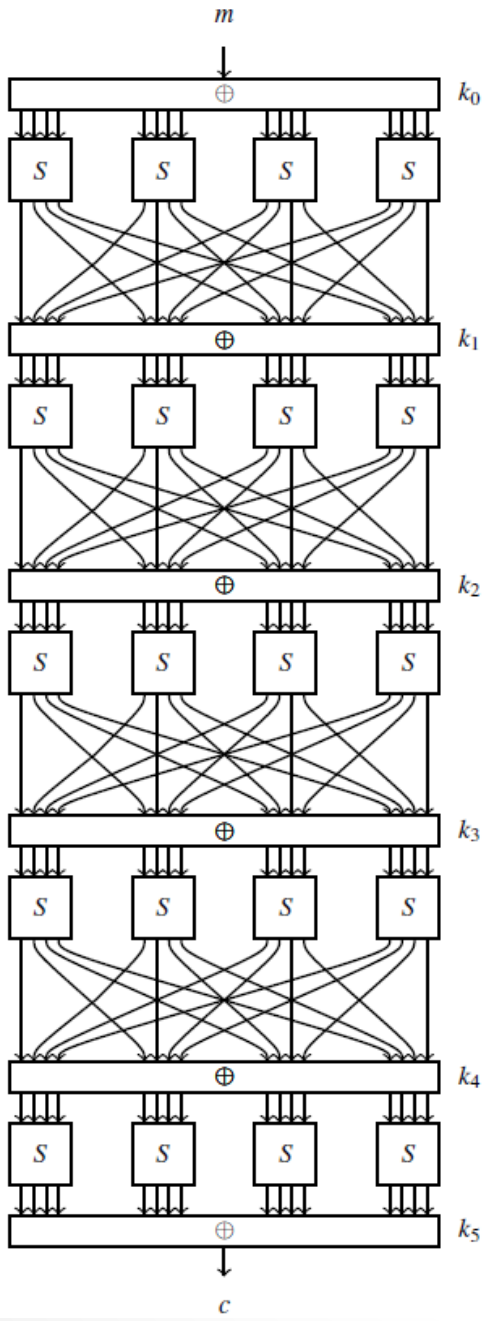
Spájanie charakteristík

- $(0,0,2,0) \xrightarrow{R} (0,0,2,0)$
- $(0,0,2,0) \xrightarrow{R} (0,0,2,0)$
- $(0,0,2,0) \xrightarrow{R} (0,0,2,0)$
- $(0,0,2,0) \xrightarrow{R} (0,0,2,0)$
- $P = (\frac{6}{16})^4 = \frac{135}{4096}$

Zavedenie diferencií

- $(\alpha_1,\alpha_2,\alpha_3,\alpha_4) \xrightarrow{S} (\beta_1,\beta_2,\beta_3,\beta_4)$
- $(\beta_1,\beta_2,\beta_3,\beta_4) \xrightarrow{P} (\gamma_1,\gamma_2,\gamma_3,\gamma_4)$
- $\boldsymbol{(\alpha_1,\alpha_2,\alpha_3,\alpha_4) \xrightarrow{R} (\gamma_1,\gamma_2,\gamma_3,\gamma_4)}$
- $(0,0,2,0) \xrightarrow{R} (0,0,2,0) \xrightarrow{R} (0,0,2,0) \xrightarrow{R} (0,0,2,0) \xrightarrow{R} (0,0,2,0)$
- $(0,0,2,0) \xrightarrow{R} \boldsymbol{?} \xrightarrow{R} \boldsymbol{?} \xrightarrow{R} \boldsymbol{?} \xrightarrow{R} (0,0,2,0)$
- $(0,0,2,0) \xrightarrow{R} (0,0,0,2) \xrightarrow{R} (0,0,0,1) \xrightarrow{R} (0,0,1,0) \xrightarrow{R} (0,0,2,0)$
- $(0,0,2,0) \xrightarrow{R} (0,0,0,2) \xrightarrow{R} (0,0,1,0) \xrightarrow{R} (0,0,2,0) \xrightarrow{R} (0,0,2,0)$
- $(0,0,2,0) \xrightarrow{R} (0,0,2,0) \xrightarrow{R} (0,0,0,2) \xrightarrow{R} (0,0,1,0) \xrightarrow{R} (0,0,2,0)$

CipherFour



Δ in \ Δout

	0	1	2	3	4	5	6	7	8	9	a	b	c	d	e	f
0	16	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	6	-	-	-	-	2	-	2	-	-	2	-	4	-
2	-	6	6	-	-	-	-	-	-	2	2	-	-	-	-	-
3	-	-	-	6	-	2	-	-	2	-	-	-	4	-	2	-
4	-	-	-	2	-	2	4	-	-	2	2	2	-	-	2	-
5	-	2	2	-	4	-	-	4	2	-	-	2	-	-	-	-
6	-	-	2	-	4	-	-	2	2	-	2	2	2	-	-	-
7	-	-	-	-	-	4	4	-	2	2	2	2	-	-	-	-
8	-	-	-	-	-	2	-	2	4	-	-	4	-	2	-	2
9	-	2	-	-	-	2	2	2	-	4	2	-	-	-	-	2
a	-	-	-	-	2	2	-	-	-	4	4	-	2	2	-	-
b	-	-	-	2	2	-	2	2	2	-	-	4	-	-	2	-
c	-	4	-	2	-	2	-	-	2	-	-	-	-	-	6	-
d	-	-	-	-	-	-	2	2	-	-	-	-	6	2	-	4
e	-	2	-	4	2	-	-	-	-	-	2	-	-	-	-	6
f	-	-	-	-	2	-	2	-	-	-	-	-	-	10	-	2

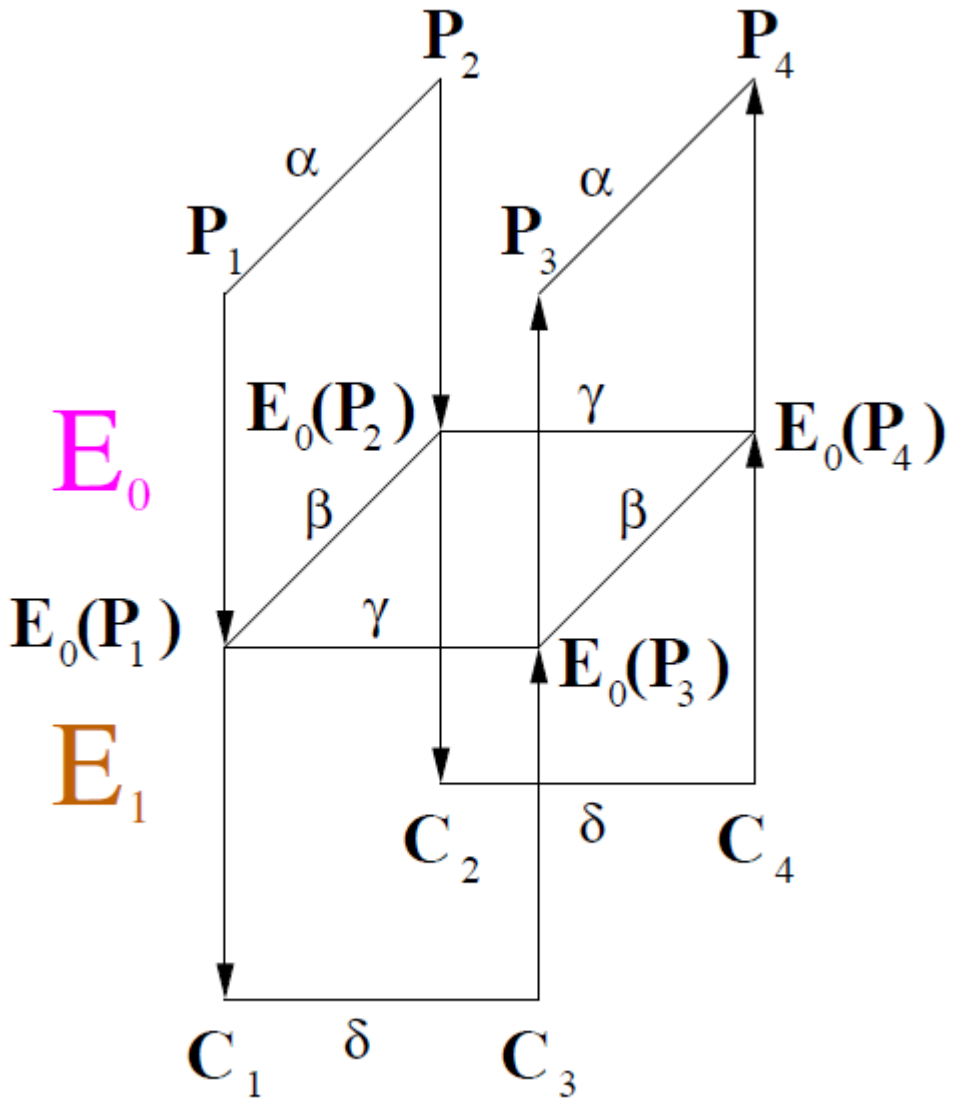
Filtrovanie

- $(0,0,2,0) \xrightarrow{S} (0,0,h,0)$
- $h \in \{1,2,9,a\}$
- $\frac{5310}{65536} \approx 0.08$ - diferencia
- $\frac{7387}{65536} \approx 0.11$ - filtrovanie
- $t \times 0.08$ - diferencia
- $t \times 0.11$ - filter
- $t \times (0.03)$ - chyba

Útok na šifru KASUMI
POPIS ÚTOKU

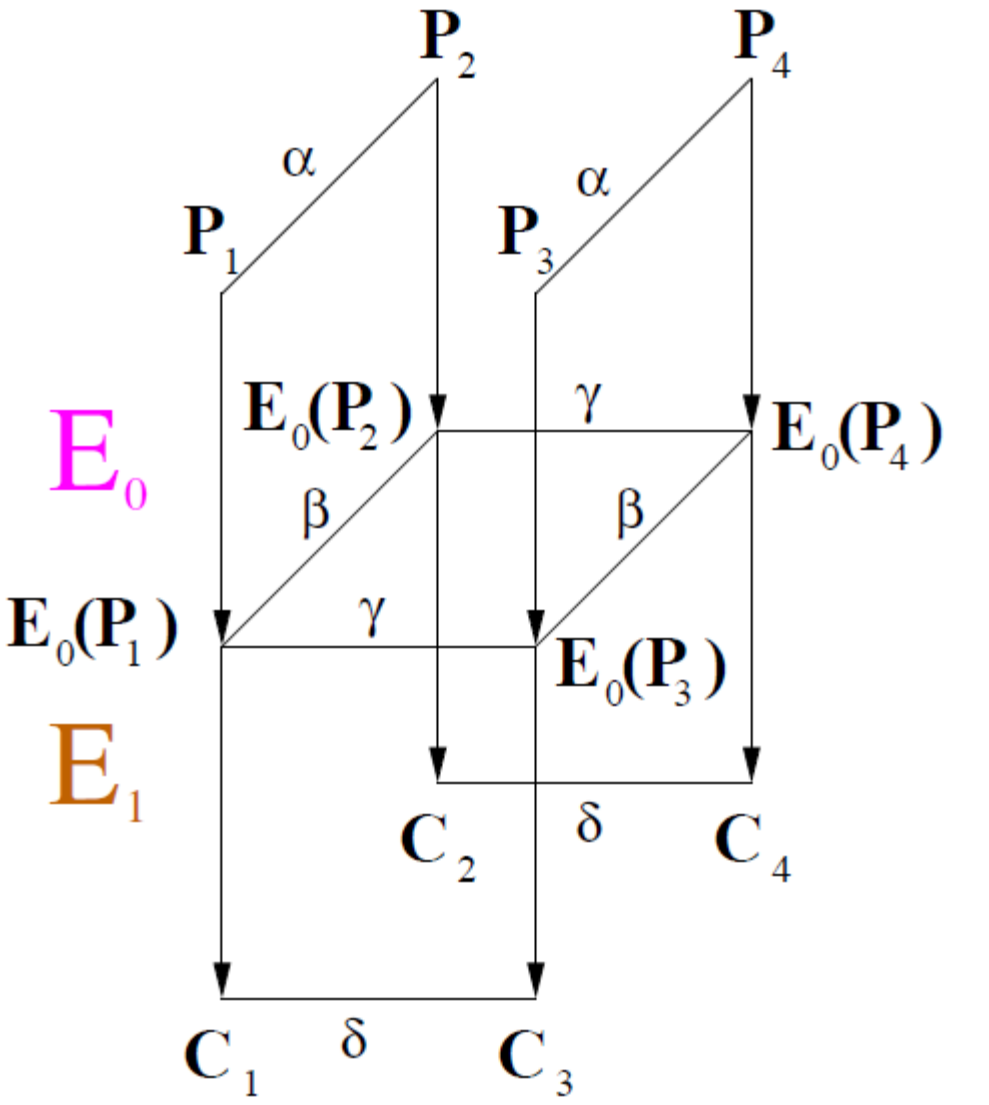
Boomerang Attack

- $p^2 q^2$
- Dobré krátke diferencie
- Zlé dlhé diferencie



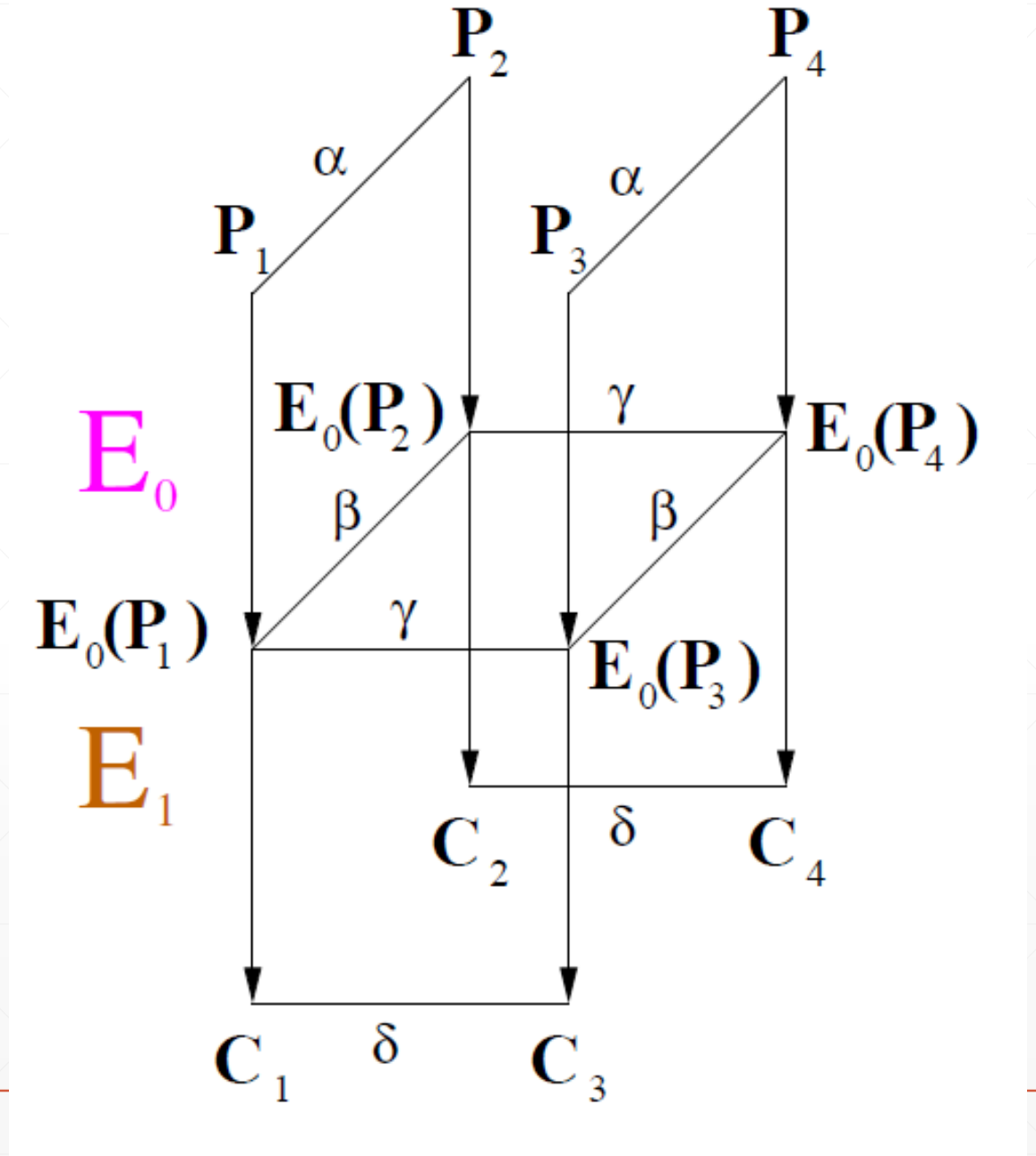
Amplified Boomerang Attack

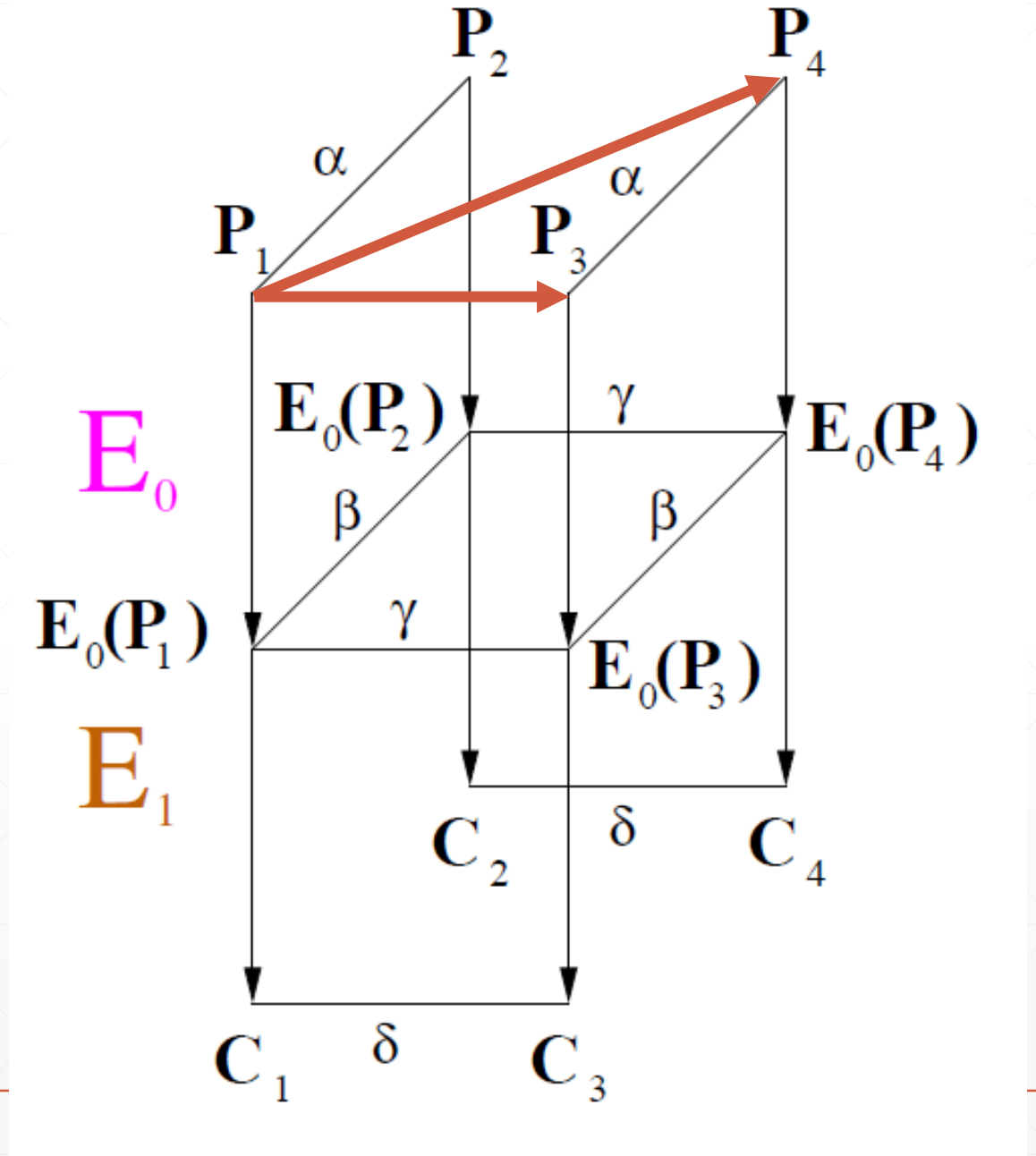
- Zašifruj veľa textu a dúfaj v to, že nejaký bude spĺňať podmienku BA
- $2^{-n-1}p^2q^2$ - pravd. správneho páru
- $2^{-n-1}p^2q^2N^2$
- Aspoň $2^{\frac{n}{2}+1}$ plaintextov



Rectangle Attack

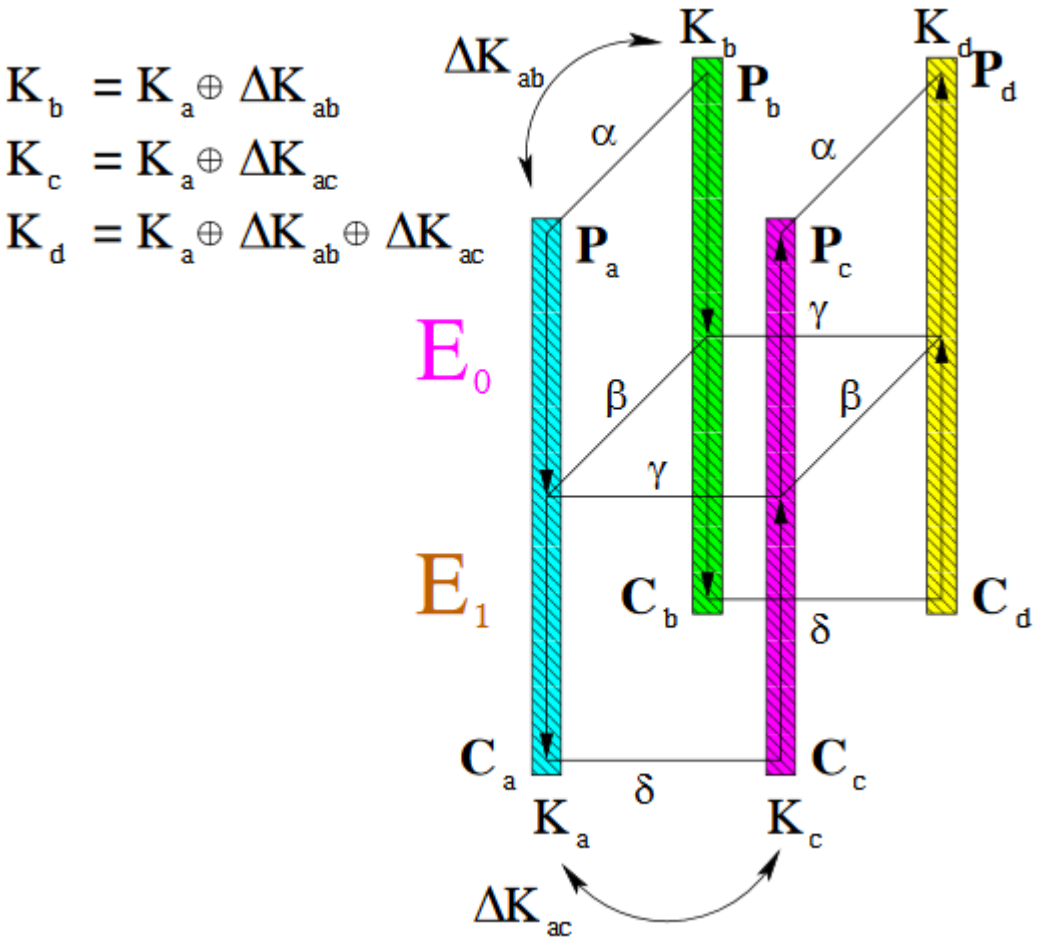
- Rozšírený Amplified Boomerang Attack – len analýzou $(\gamma \rightarrow \delta)$ v E_1;
- Štvorica$\big((P_1, P_2), (P_3, P_4)\big)$ a k tomu príslušný šifrovaný text $\big((C_1, C_2), (C_3, C_4)\big)$ také, že $P_1 \oplus P_2 = P_3 \oplus P_4 = \alpha$ a $C_1 \oplus C_3 = C_2 \oplus C_4 = \delta$, kde α je vstupná diferencia do E_0 a δ je výstupná diferencia z E_1
- Využijeme všetky možné γ keď platí $Z_1 \oplus Z_3 = Z_2 \oplus Z_4 = \gamma$ a $Z_1 \oplus Z_2 = \beta$, kde $Z_i = E_0(P_i)$ $(\gamma \rightarrow \beta)$ v E_1
- Využijeme všetky možné β keď platí $Z_1 \oplus Z_2 = Z_3 \oplus Z_4$ a $Z_1 \oplus Z_3 = \gamma$
- „Pre každý pár je k dispozícii viac párov“ $\big((P_1, P_2), (P_4, P_3)\big)$ a $\big((P_1, P_2), (P_3, P_4)\big)$


P2
P4
α
α
P1
P3
E0(P2)
γ
E0(P4)
E0
β
β
E0(P1)
γ
E0(P3)
E1
C2
δ
C4
C1
δ
C3


P2
P4
α
α
P1
P3
E0
E0(P2)
γ
E0(P4)
β
β
E0(P1)
γ
E0(P3)
E1
C2
δ
C4
C1
δ
C3

Related-Key Boomerang Attack

- Vyber náhodne P_a,
  a spočítaj $P_b = P_a \oplus \alpha$
- Požiadaj o šifrovanie $C_a = E_{K_a}(P_a)$
  a $C_b = E_{K_b}(P_b)$
- Spočítaj $C_c = C_a \oplus \delta$ a $C_d = C_b \oplus \delta$
- Požiadaj dešifrovať $P_c = E_{K_c}^{-1}(C_c)$
  a $P_d = E_{K_d}^{-1}(C_d)$
- Skontroluj, či $P_c \oplus P_d = \alpha$



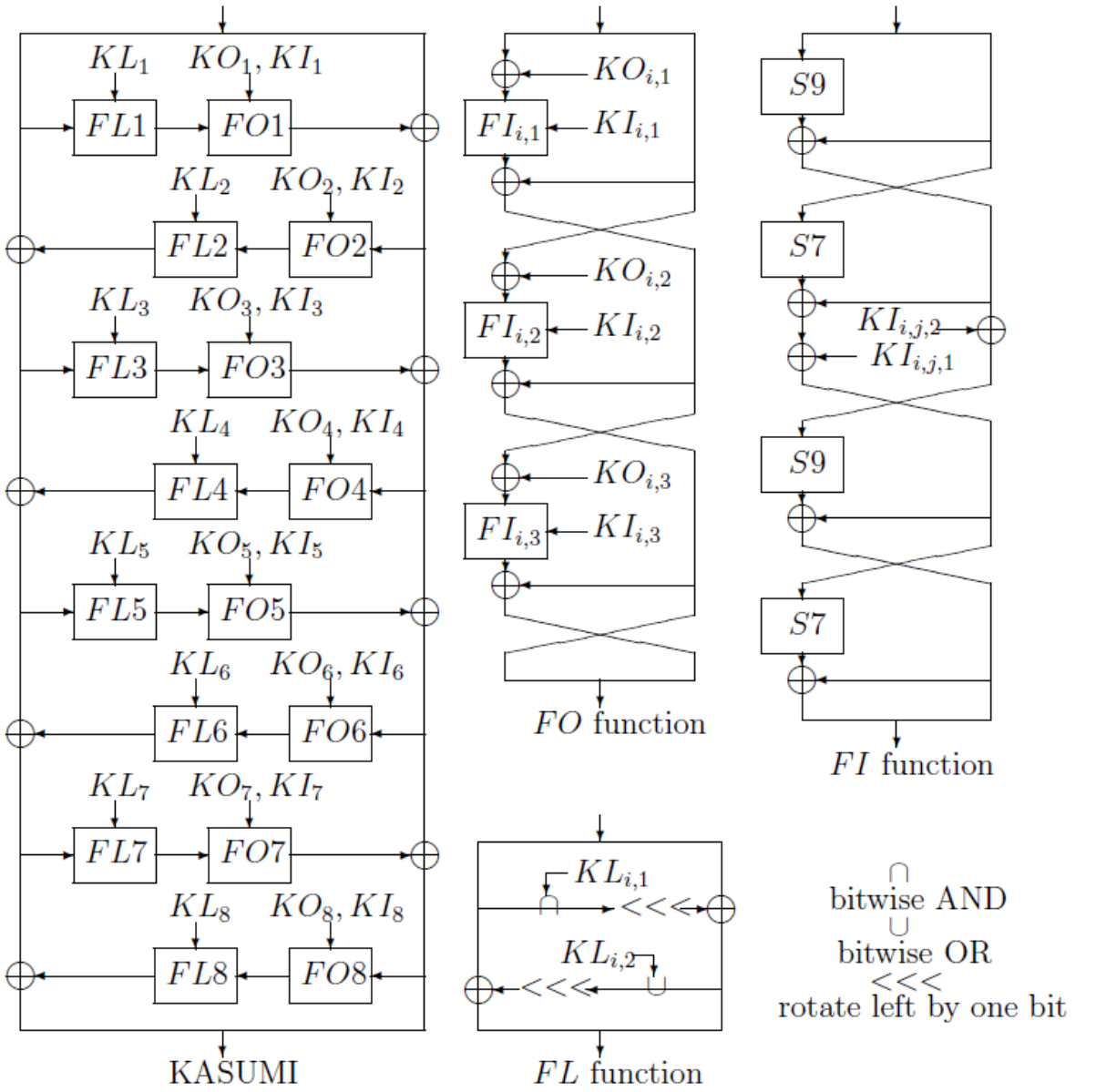
Related-Key Rectangle Attack

- $K_a, K_b = K_a \oplus K_{ab}$, $K_c = K_a \oplus K_{ac}$, $K_d = K_a \oplus K_{ad}$
- Vyber N otvorených párov ($P_a, P_b = P_a \oplus \alpha$) a požiadaj zašifrovanie P_a kľúčom K_a a P_b kľúčom K_b
- Vyber N otvorených párov ($P_c, P_d = P_c \oplus \alpha$) a požiadaj zašifrovanie P_c kľúčom K_c a P_d kľúčom K_d
- Najdi štvorice (P_a, P_b, P_c, P_d) a odpovedajúce (C_a, C_b, C_c, C_d) splňujúce $C_a \oplus C_c = C_b \oplus C_d = \delta$
- Lepšie pravdepodobnosti útokov
- $N^2 2^{-n} (pq)^2$ - správnych štvoríc

Útok na šifru KASUMI sekcia:

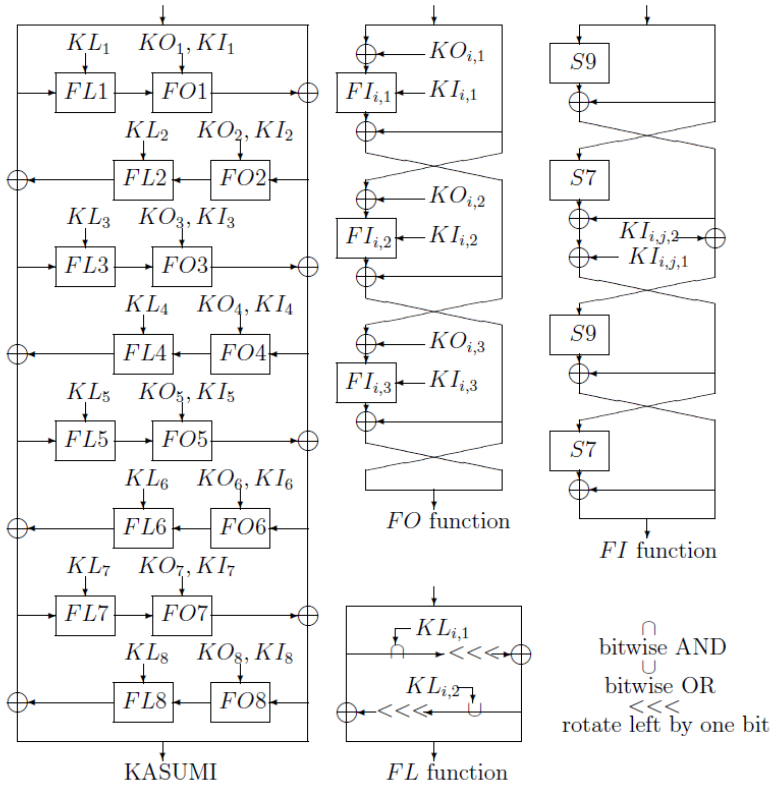
Related-Key Boomerang and Rectangle Attacks on the Full KASUMI

KASUMI


KL_1 KO_1, KI_1
$FL1$ $FO1$
KL_2 KO_2, KI_2
$FL2$ $FO2$
KL_3 KO_3, KI_3
$FL3$ $FO3$
KL_4 KO_4, KI_4
$FL4$ $FO4$
KL_5 KO_5, KI_5
$FL5$ $FO5$
KL_6 KO_6, KI_6
$FL6$ $FO6$
KL_7 KO_7, KI_7
$FL7$ $FO7$
KL_8 KO_8, KI_8
$FL8$ $FO8$
KASUMI
$KO_{i,1}$
$FI_{i,1}$ $KI_{i,1}$
$KO_{i,2}$
$FI_{i,2}$ $KI_{i,2}$
$KO_{i,3}$
$FI_{i,3}$ $KI_{i,3}$
FO function
$KL_{i,1}$
$KL_{i,2}$
FL function
S9
S7
$KI_{i,j,2}$
$KI_{i,j,1}$
S9
S7
FI function
bitwise AND
bitwise OR
rotate left by one bit

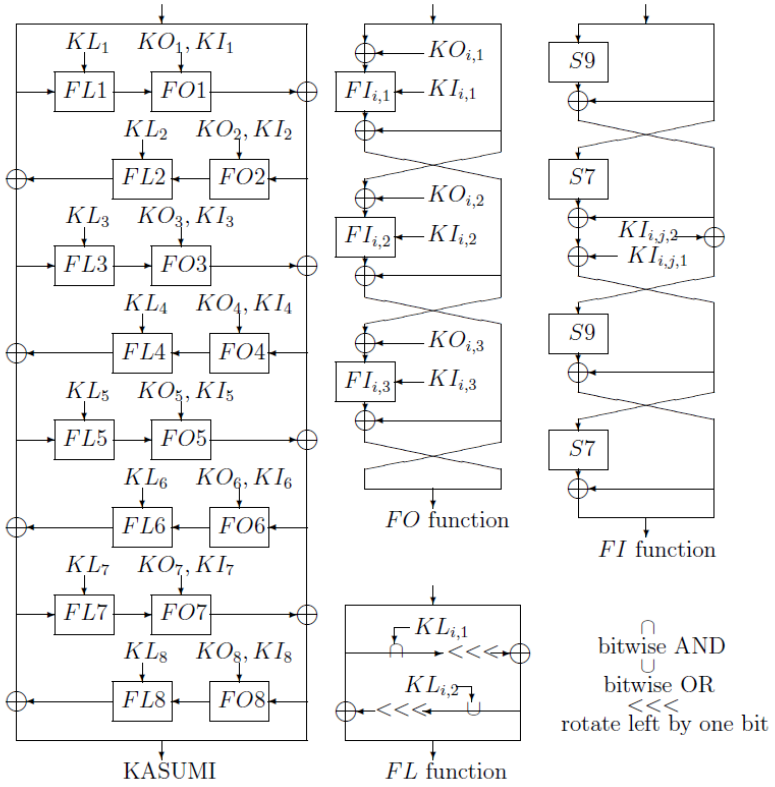
KASUMI 1-4

- $\Delta K_{ab} = (0,0,1,0,0,0,0,0)$
- Vstupná diferencia $\alpha = (0_X, (0020\ 0000)_X)$
- $\alpha = (0_X, (0020\ 0000)_X) \rightarrow (y_X, (0020\ 0000)_X)$
- $2^{-34} = \frac{1}{4}\frac{1}{2^{32}}$
- $P = (P_{LL}P_{LR}P_{RL}P_{RR})$
- $P_{LL}^0 = 0, P_{LR}^1 = 1$ – zlepšíme charakteristiku
- $\frac{1}{2^{33}}$, efektívna pravdepodobnosť $\frac{1}{2^{17}}$



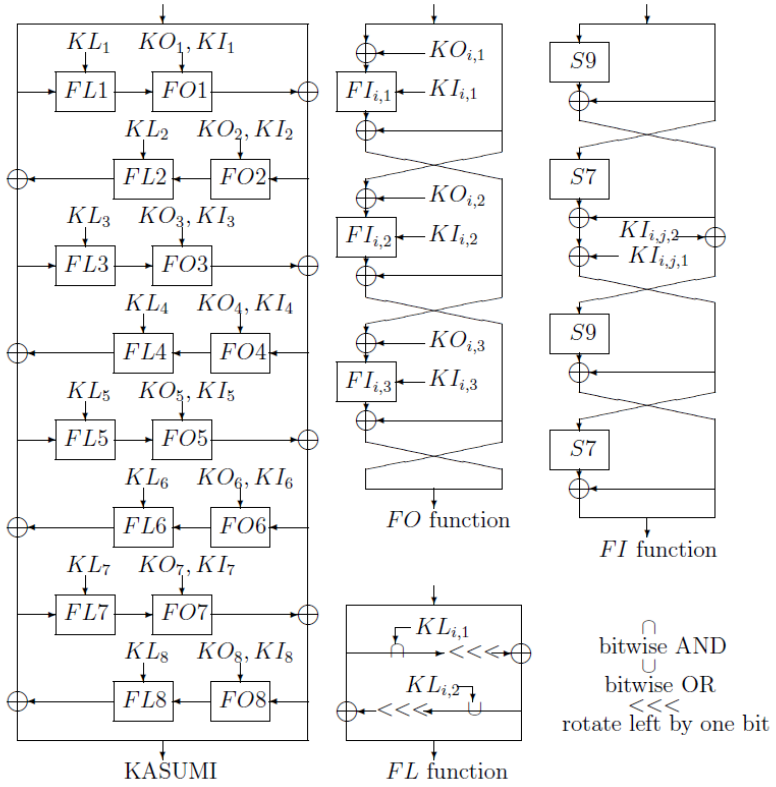
KASUMI 5-7

- $\Delta K_{ac} = (0,0,0,0,0,0,1,0)$
- Vstupná diferencia $\gamma = (0_X, (0020\ 0000)_X)$
- $\gamma = (0_X, (0020\ 0000)_X) \rightarrow (0_X, (0020\ 0000)_X)$
- $\frac{1}{4}$, efektívna je $\frac{1}{4}$



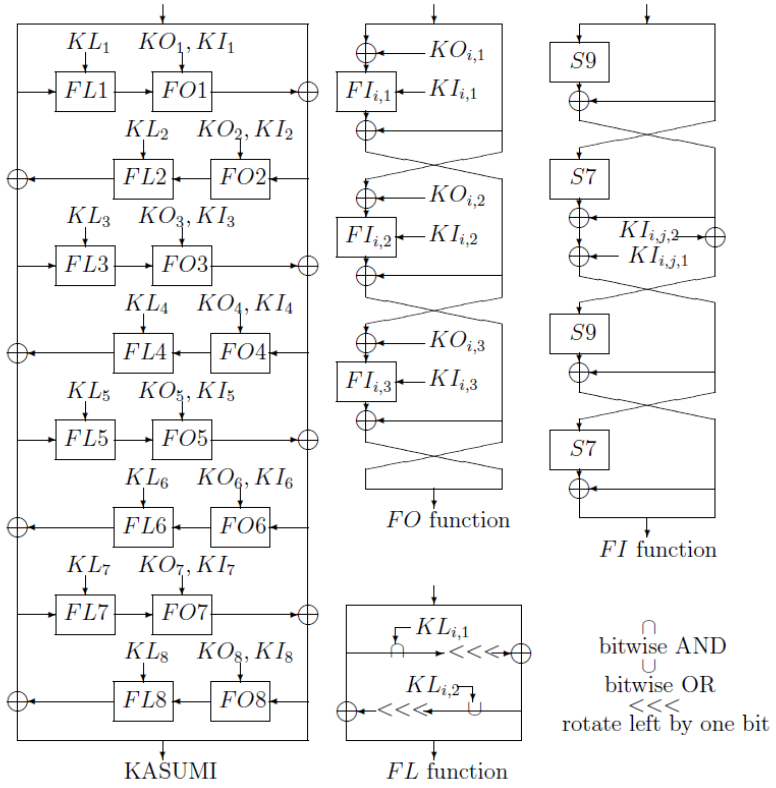
KASUMI ÚTOK

- $K_a, K_b = K_a \oplus K_{ab}$, $K_c = K_a \oplus K_{ac}$, $K_d = K_a \oplus K_{ad}$
- Potrebujeme 2^{51} - otvorených textov
- Celkovo štvoríc máme 2^{102}, potom dostávame 1 správny „obdĺžnik“
- Algoritmus:
  - 2^{51} šifrovaní: $(P_a, P_b = P_a \oplus \alpha)$, $P^0_{a_{LL}} = 0$, $P^1_{a_{LR}} = 1$, $\mathrm{E}(P_a, K_a)$, $\mathrm{E}(P_b, K_b)$
    Index: $\left(C_{a_{RL}} C_{a_{RR}} C_{b_{RL}} C_{b_{RR}}\right)$
  - 2^{51} šifrovaní: $(P_c, P_d = P_c \oplus \alpha)$, $P^0_{c_{LL}} = 0$, $P^1_{c_{LR}} = 1$, $\mathrm{E}(P_c, K_c)$, $\mathrm{E}(P_d, K_d)$
    Index: $\left(C_{c_{RL}} \oplus 0020_X, C_{c_{RR}} C_{d_{RL}} \oplus 0020_X, C_{d_{RR}}\right)$ (zhoduje sa diferencia?)



KASUMI ÚTOK

- $(C_{c_{RL}} \oplus 0020_X, C_{c_{RR}} C_{d_{RL}} \oplus 0020_X, C_{d_{RR}})$
  - Nájdeme (P_a, P_b), pokračujeme štvoricou (P_a, P_b, P_c, P_d)
- 2^{38} približne bude vyhovovať
- Tipneme si kľúč $(KO_{8,1}, KI_{8,1})$ a vydedukujeme $KL_{8,2}$ - je možné vypočítať vstupné a výstupne diferencie do OR funkcie (spor)
- Tipneme si kľúč $(KO_{8,3}, KI_{8,3})$ a vydedukujeme $KL_{8,2}$ - spočítame diferencie vstupu a výstupu
- Pre všetky vyhovujúce kombinácie urob šifrovanie a over výsledok



KASUMI ÚTOK – ANALÝZA

- Ohdadovanie $KL_{8,2}$ – 2^{-16} - zlých kľúčov

OR — $KL_{8,2}$

(X_1', Y_1')	(X_2', Y_2') (0,0)	(0,1)	(1,0)	(1,1)
(0,0)	{0,1}	—	1	0
(0,1)	—	—	—	—
(1,0)	1	—	1	—
(1,1)	0	—	—	0

AND — $KL_{8,1}$

(X_1', Y_1')	(X_2', Y_2') (0,0)	(0,1)	(1,0)	(1,1)
(0,0)	{0,1}	—	0	1
(0,1)	—	—	—	—
(1,0)	0	—	0	—
(1,1)	1	—	—	1

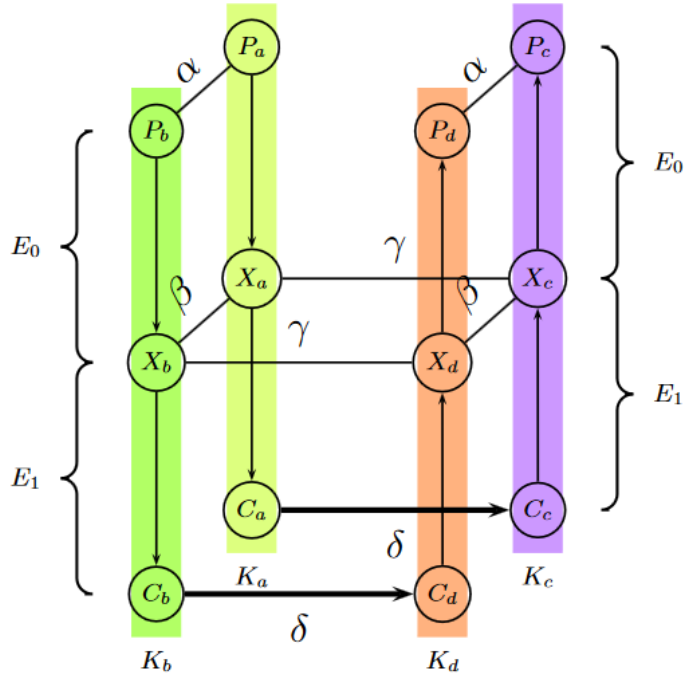
* The two bits of the differences are denotes by (input difference, output difference): (X_1', Y_1') for one pair and (X_2', Y_2') for the other.

KASUMI ÚTOK – ANALÝZA

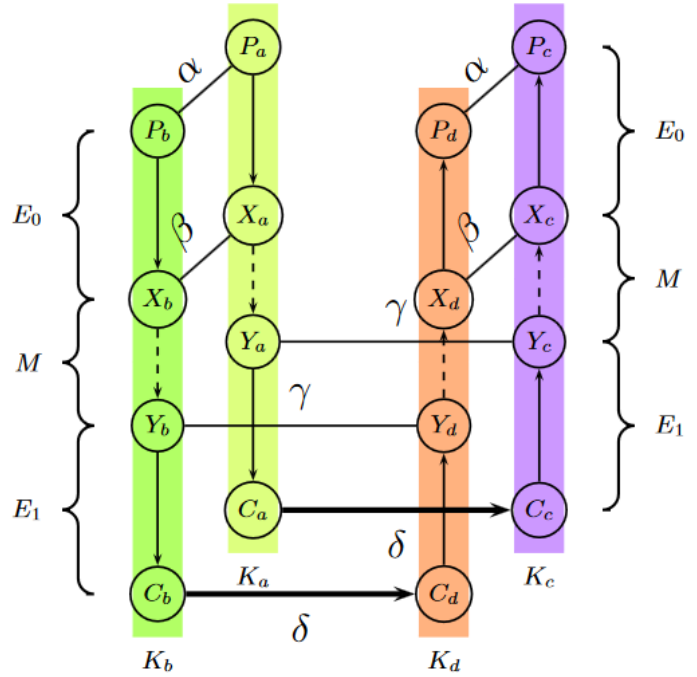
- Ohdadovanie $KL_{8,2} - 2^{-16}$ - zlých kľúčov
- $\mathbf{2^{38}2^{32} = 2^{70}; 2^{70}2^{-16} = 2^{54}}$
- $\mathbf{2^{54}2^{32} = 2^{86}; 2^{86}2^{-16} = 2^{70}}$ - pre 96 bitový kľúč ☺
- Dokončiť zvyšných 32 bitov
  - $\mathbf{2^{102}}$ operácii pri 128 bitovom kľúči
- Vylepšenia:
  - Pri šifrovaní $\mathbf{2^{52,6}}$ vstupných textov = $\mathbf{2^{86,6}}$
  - Analýzov vieme dostať $\mathbf{2^{76,1}}$ - viac informácií v mojej práci ☺

KASUMI ÚTOK 2

- Sandwich attack
- 2^{32} časová zlozitosť
- 2^{30} pamäťová zlozitosť
- 2^{25} šifrových textov



A Related-Key Boomerang Quartet



A Related-Key Sandwich Quartet

Zdroj

- E. Biham, O, Dunkelman: Techniques for Cryptanalysis of Block Ciphers (Information Security and Cryptography), Springer, 2017, ISBN 978-3642172311
- DUNKELMAN, Orr; KELLER, Nathan; SHAMIR, Adi. A practical-time related-key attack on the KASUMI cryptosystem used in GSM and 3G telephony. In: *Annual Cryptology Conference*. Springer Berlin Heidelberg, 2010. p. 393-410.

Ďakujem za pozornosť.