Programming the Demirci-Selçuk Meet-in-the-Middle Attack with Constraints

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Outlines

Outline

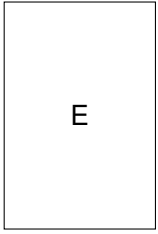
Demirci-Selçuk MITM Attack

- Demirci-Selçuk MITM, FSE 2008 [DS08].
- Various Creative Techniques:
  Differential Enumeration, Key Bridging, Key Dependent Sieve,. . . ,
  [DKS10, DFJ13, DF13, DF16, LJ16]
- General Model, Dedicated Search Algorithm [LWWZ13, DF13, DF16]

Automatic Searching methods

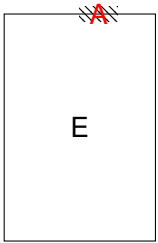
- MILP,CP,SAT,SMT
- Differential, Linear, Integral, 3-subset MITM ...
  [KLT15, SHW+14, ST17, CJF+16, XZBL16, GMS16, Sas18]

MITM Distinguisher



MITM Distinguisher

$\delta(A)$-set: $\{P^0, P^1, \ldots, P^{N-1}\}$



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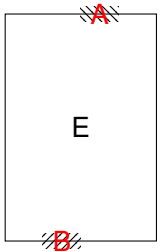

$\{C^0, C^1, \ldots, C^{N-1}\}$

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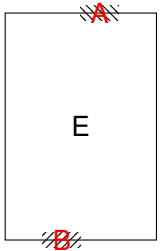
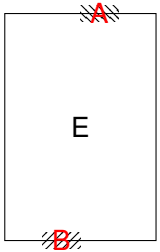


$\{C^0, C^1, \ldots, C^{N-1}\}$

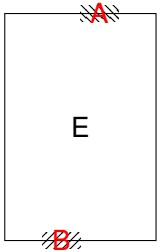
$\Delta_{\mathrm{E}}(A, B)$: $\{C^0[B] \oplus C^1[B], C^0[B] \oplus C^2[B], \ldots, C^0[B] \oplus C^{N-1}[B]\}$

Distinguisher of MITM



Distinguisher of MITM

- Random: $\mathcal{N}_R$



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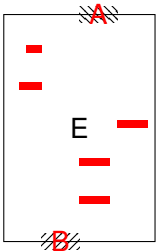
- Random: $\mathcal{N}_R$
- Block Cipher : $\mathcal{N}_E$ (saved into a hash table)



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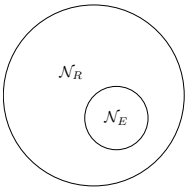

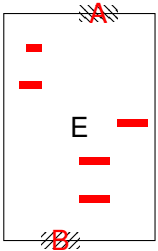

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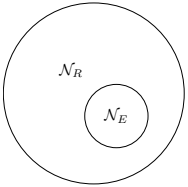
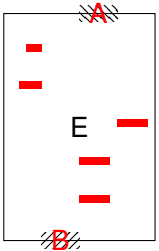
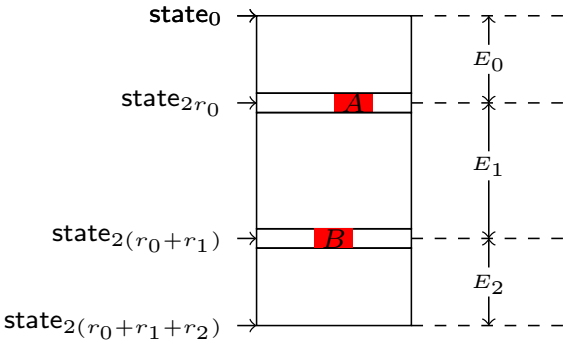




Distinguisher:$(A, B, \mathcal{N}_E)$

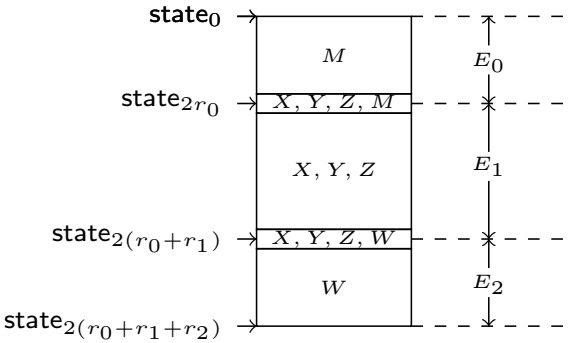
Key Recovery Attack of MITM

- A cipher is divided in three keyed permutations: E_0, E_1, E_2
- Construct distinguisher $(A, B, \mathcal{N}_E)$ at E_1



Outline

Variables



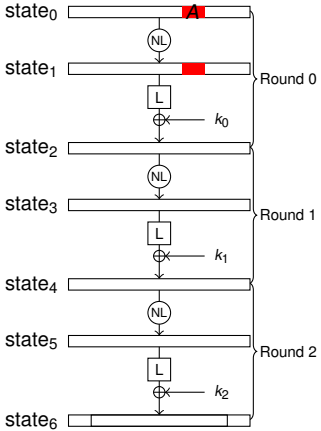
- `Var(X)` describe the forward differential
- `Var(Y)` describe the backward determination
- `Var(Z)` model the relation between `Var(X)` and `Var(Y)`

Forward differential

Variables Var(X)

$$X_r[j] = 0 \text{ iff } P_r^0[j] \oplus P_r^i[j] = 0, \forall i \in 1, \ldots, N-1.$$

- Var(X) for $\texttt{state}_0$
  $X_0[j] = 1$ iff j in A.
- X_r propagate to X_{r+1} with probability 1



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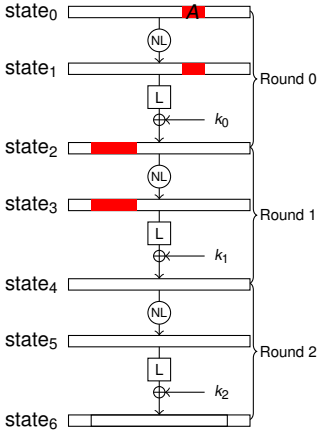

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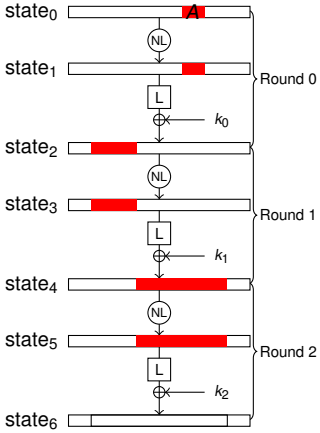

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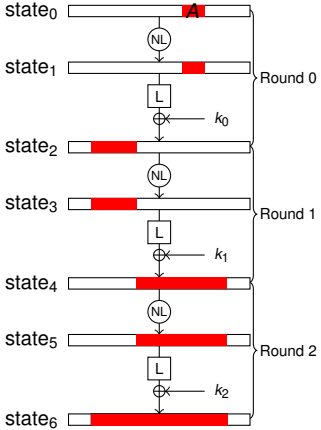
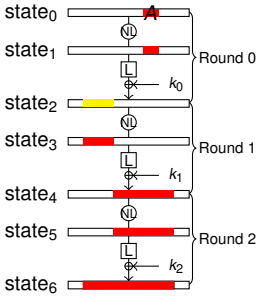


Property of forward differential

values of P^0 at the yellow states

$$\Downarrow$$

$$P_6^0 \oplus P_6^i,\ \forall i \in \{1, 2, \ldots, N-1\}$$



$\{P^0[A_{2r}]\}_{r\in 1,2}$ determine $P_6^0 \oplus P_6^i$

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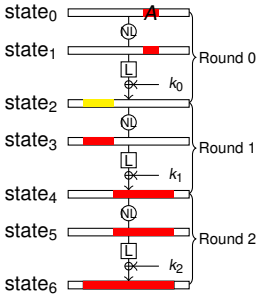

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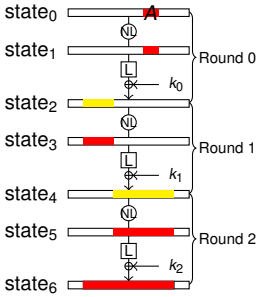

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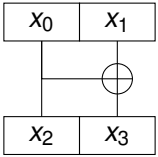

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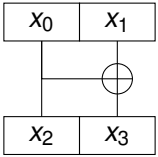

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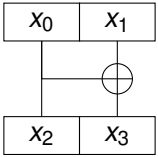

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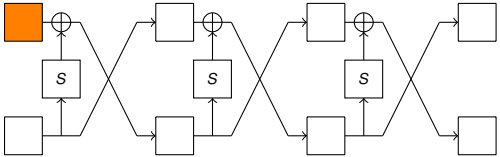

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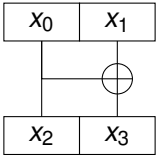

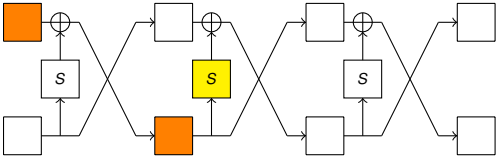

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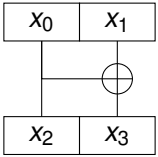

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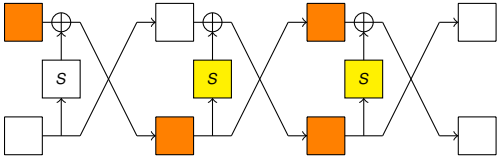

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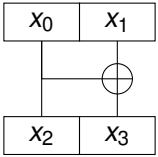

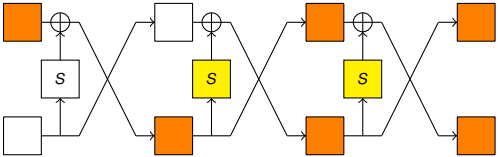

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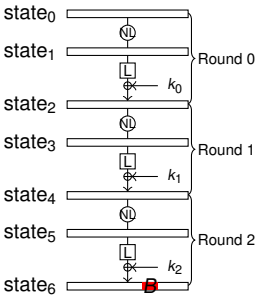
Backward determination

Variables Var(Y)

- Var(Y) for $\texttt{state}_6$
  $Y[j] = 1$ iff $j \in B$.
- Difference at B are determined by these colored positions



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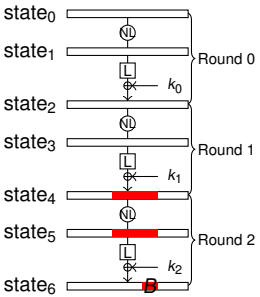

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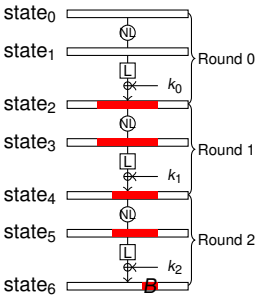

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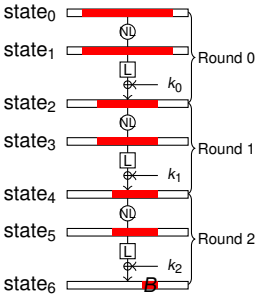
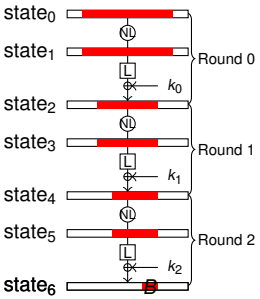


Property of backward determination

Values of P^0 at the yellow nibbles

$$\Downarrow$$

$$P_6^0 \oplus P_6^i[B], \forall i \in \{1, 2, \ldots, N\}$$



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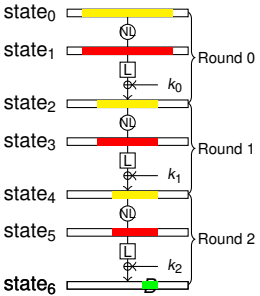

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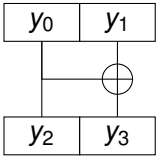

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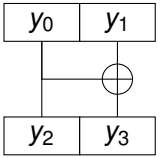

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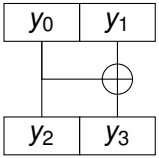

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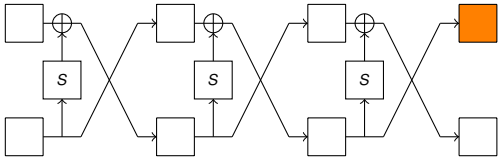

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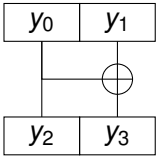

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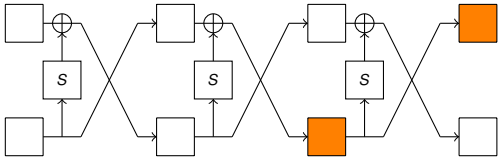

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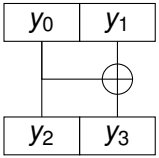

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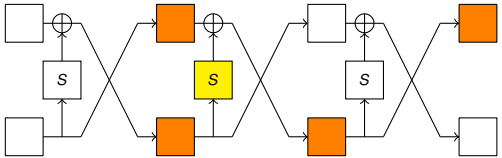

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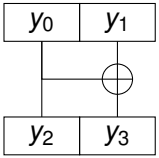

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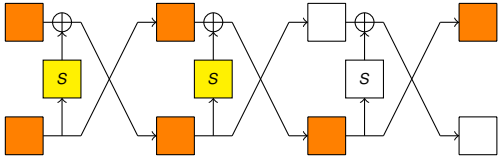

Constraints for Var(Z)

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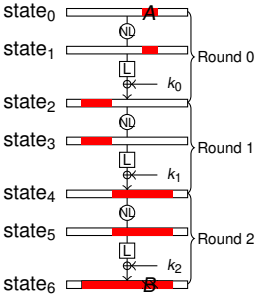
$$Z_r[j] = 1 \text{ iff } X_r[j] = Y_r[j] = 1$$



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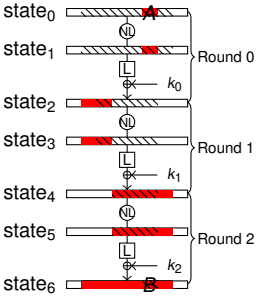

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Application to SKINNY

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- $MC = \begin{pmatrix} 1 & 0 & 1 & 1 \\ 1 & 0 & 0 & 0 \\ 0 & 1 & 1 & 0 \\ 1 & 0 & 1 & 0 \end{pmatrix}$

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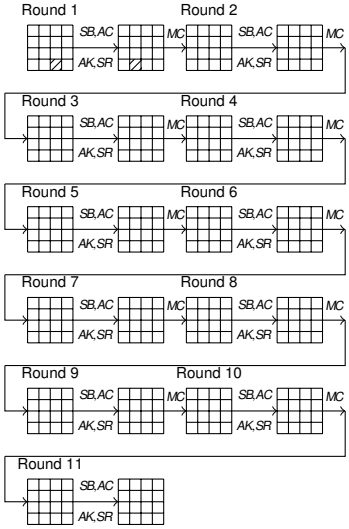

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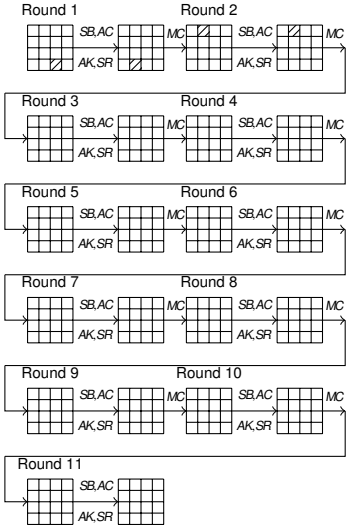

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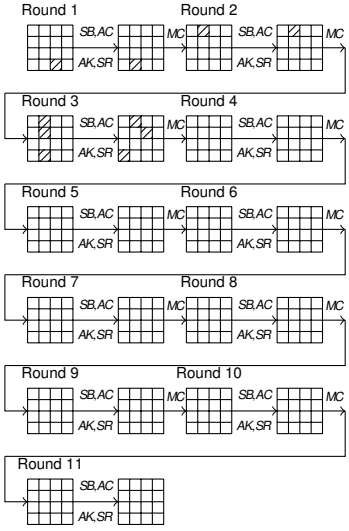

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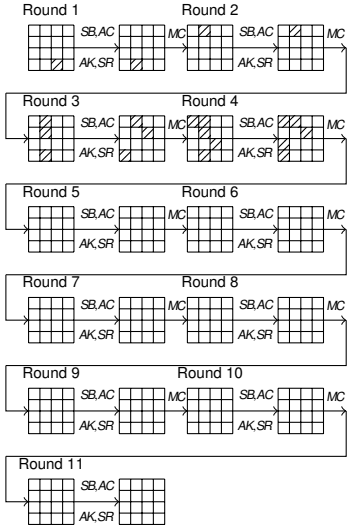

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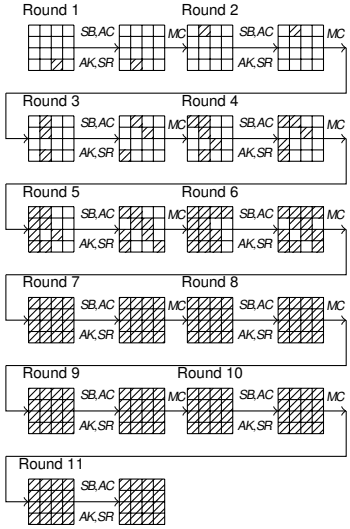

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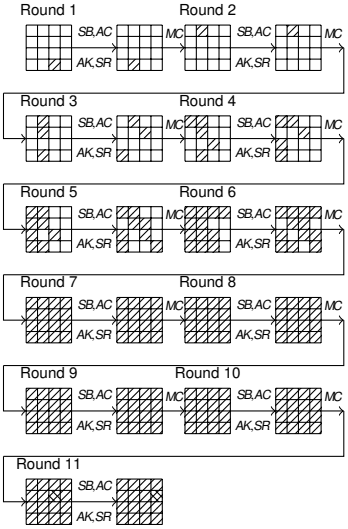

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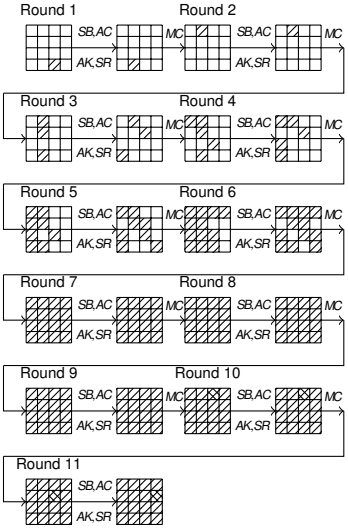

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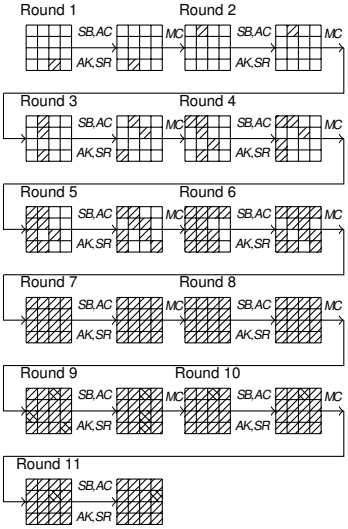

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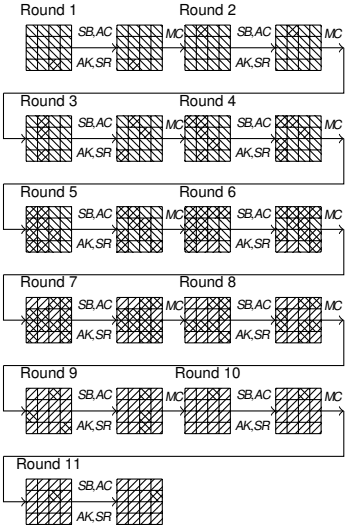

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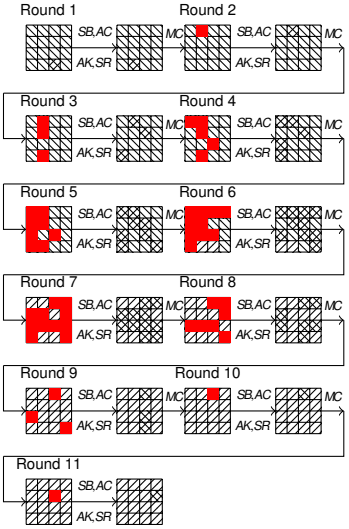

New 0-1 variables Var(M) for E_0

Var(M): Determine the plaintext structure

- $M_{2r_0} = X_{2r_0}$
- backward differential propagation with probability 1.
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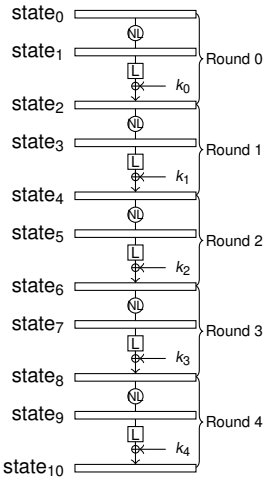

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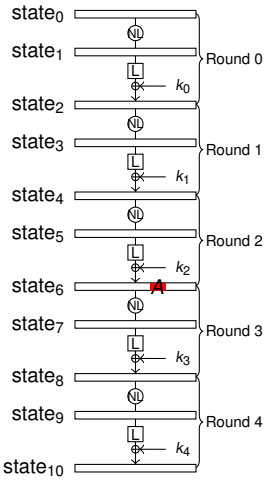

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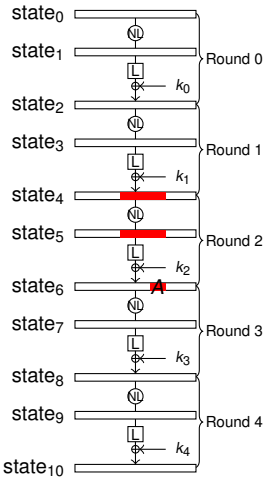

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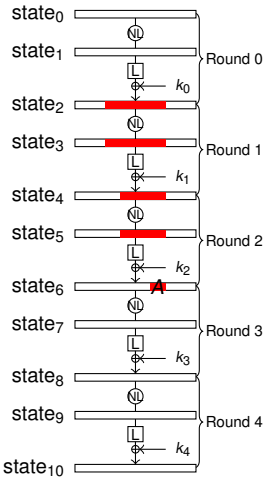

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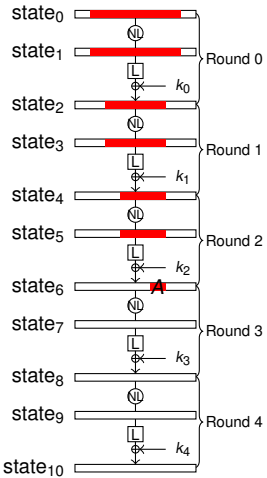
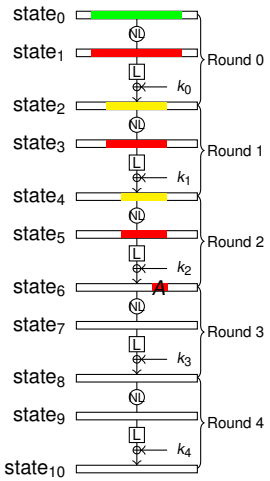


Property of backward differential

- Guess the values of P^0 at the yellow state
- obtain $\{P^0, P^1, \ldots, P^{N-1}\}$ s.t. $\{P_6^0, P_6^1, \ldots, P_6^{N-1}\}$ is $\delta(A)$-set



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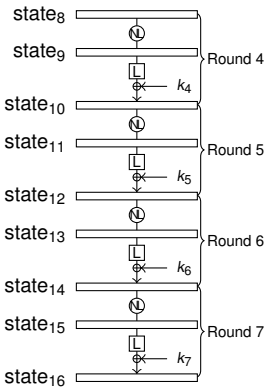

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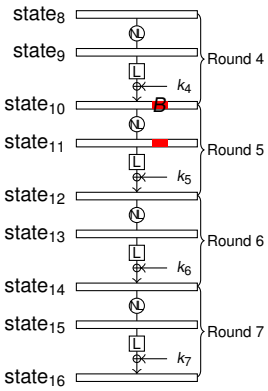

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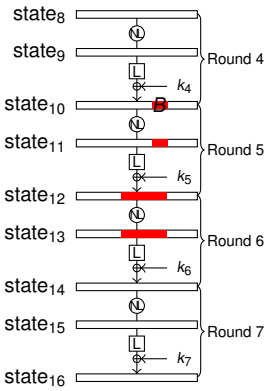

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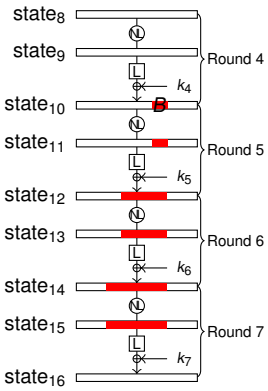

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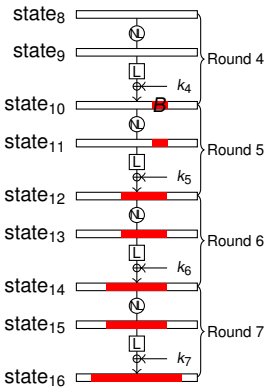
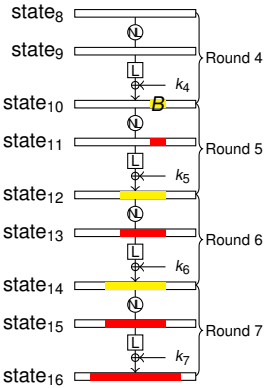


Property of Forward Determination

Guess the values of P^0 at yellow states

$\Downarrow$

Obtain sequence $\Delta_{\mathrm{E}}(A, B)$ at $\mathtt{state}_{10}$



Examples for Var(M) and Var(W)

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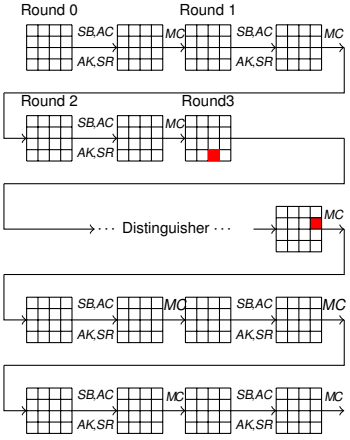

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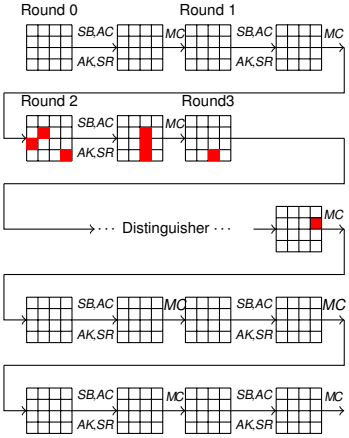

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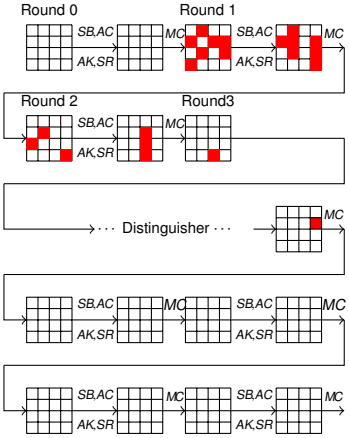

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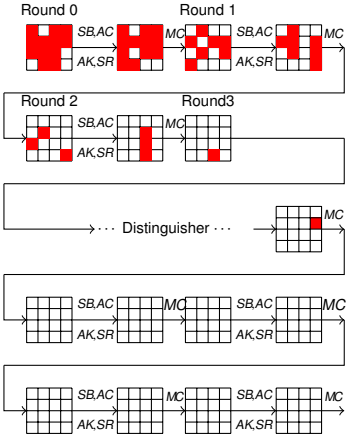

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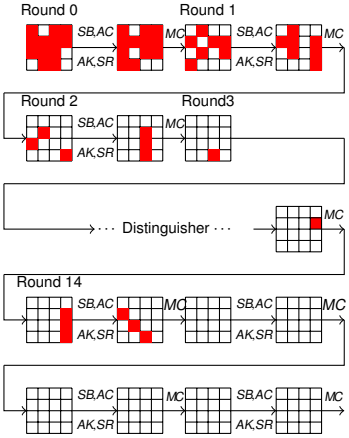
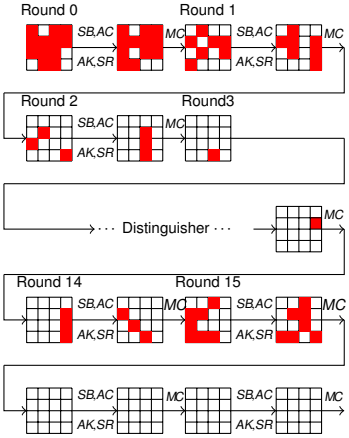


Examples for Var(M) and Var(W)

Var(M): Backward differential

$$MC^{-1} = \begin{pmatrix} 0 & 1 & 0 & 0 \\ 0 & 1 & 1 & 1 \\ 0 & 1 & 0 & 1 \\ 1 & 0 & 0 & 1 \end{pmatrix}$$

Var(W): Forward determination



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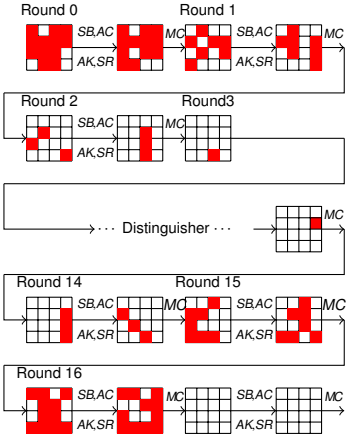

Examples for Var(M) and Var(W)

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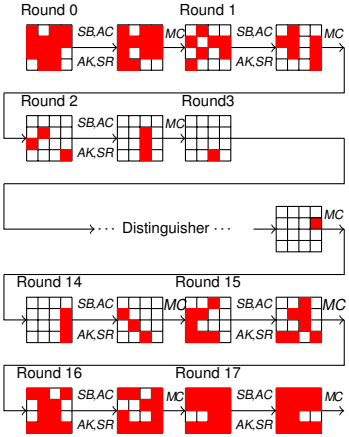
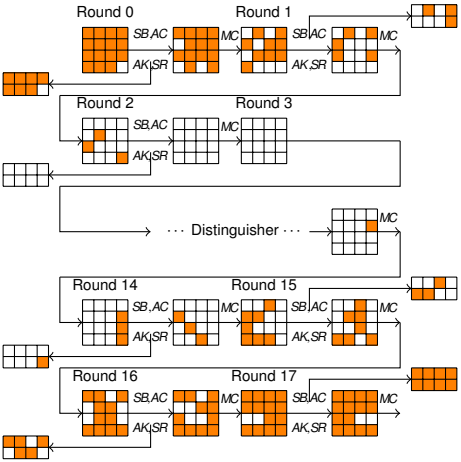


Guessed Subkeys

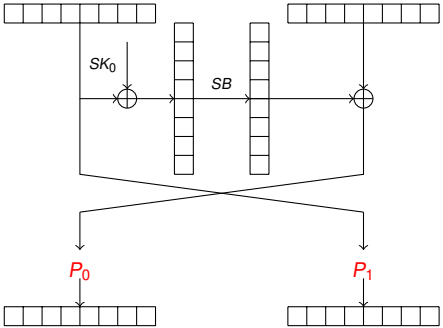


Results

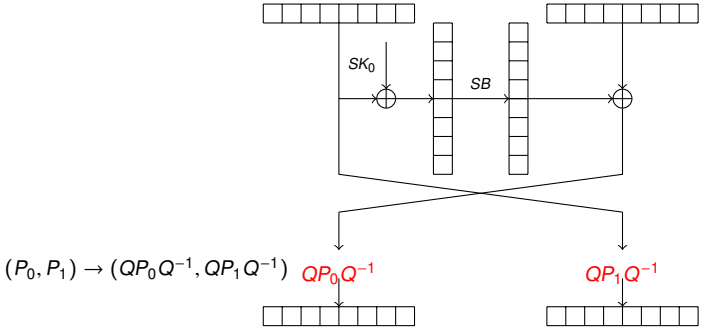
Target	Rounds	Time	Data	Memory	Method	Ref
LBlock	$11+10$	$2^{70.20}$	2^{48} CP	$2^{61.91}$	$\mathcal{DS}$-MITM	Sect. 7.2
	$9+0$	$2^{74.5}$	–	–	$\mathcal{DS}$-MITM Dist.	[43]
	23	$2^{74.5}$	$2^{59.5}$CP	$2^{74.3}$	ID	[47]
	23	$2^{75.36}$	2^{59}CP	2^{74}	ID	[48]
	23	2^{72}	$2^{62.1}$ Kp	2^{60}	MultiD ZC	[47]
	23	2^{76}	$2^{62.1}$ Kp	2^{60}	MultiD ZC	[49]
TWINE80	$11+9$	$2^{77.44}$	2^{32} CP	$2^{82.91}$	$\mathcal{DS}$-MITM	Sect. 7.3
	23	$2^{79.09}$	$2^{57.85}$ CP	$2^{84.06}$	ID	[50]
	23	2^{73}	$2^{62.1}$ KP	2^{60}	MultiD ZC	[47]
TWINE128	$11+14$	$2^{124.7}$	2^{48} CP	2^{109}	$\mathcal{DS}$-MITM*	[34]
	25	$2^{124.5}$	$2^{59.1}$ CP	$2^{78.1}$	ID	[34]
	25	2^{119}	$2^{62.1}$ KP	2^{60}	MultiD ZC	[47]
	25	$2^{122.12}$	$2^{62.1}$ KP	2^{60}	MultiD ZC	[49]
SKINNY-128-384	$10.5+11.5$	$2^{382.46}$	2^{96} CP	$2^{330.99}$	$\mathcal{DS}$-MITM	Sect. 7.1
	$11+11$	$2^{373.48}$	$2^{92.22}$ CP	$2^{147.22}$	ID	[51]

$\star$ We find the attacks with the same complexity.

Outline



Enumeration: $8! \cdot 8!$



Enumeration: $8! \cdot 8! \rightarrow 22 \cdot 8!$

Results

- 144 permutations: no 15-round IM Distinguisher.
- 12 permutations may be best: no 11-round `MITM` distinguisher

Outline

Conclusion

Conclusion

- modelling the `MITM` attack
- IM and `MITM` for variants cipher of LBlock and TWINE

Future Work

- Differential Enumeration
- Key Bridging
- ...

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Thanks for your attention.