Practical Attacks on Full-round FRIET

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Talked by **Senpeng Wang**

Outline

1. Description of FRIET

2. A Differential Distinguisher for Full-round FRIET-PC

3. A Linear Distinguisher for Full-round FRIET-PC

4. Practical Attacks on Full-round FRIET-AE

5. Conclusions and Future Work

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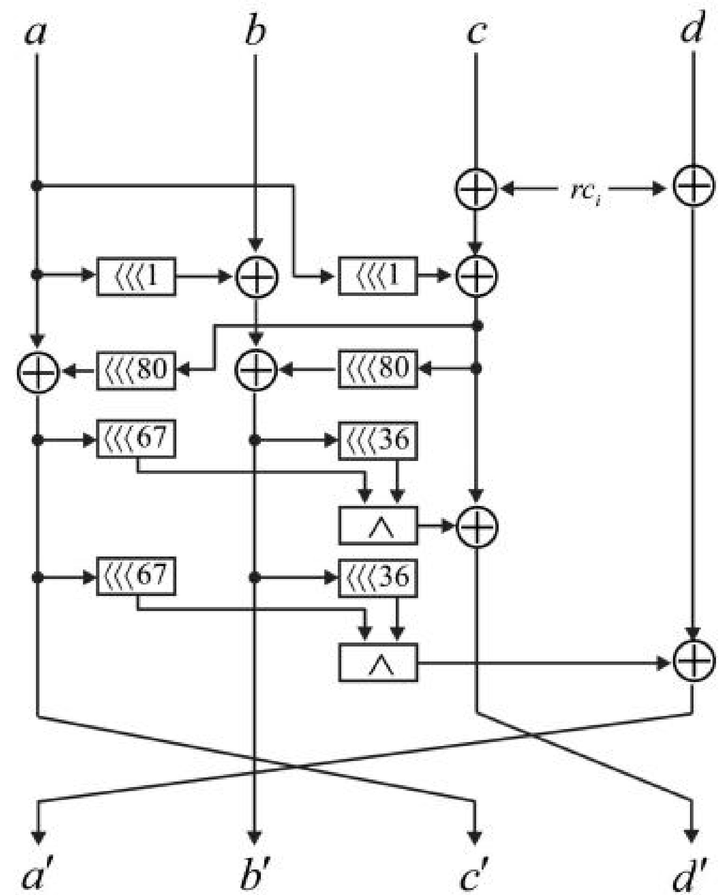
1. Description of FRIET

FRIET is an authenticated encryption scheme with built-in fault detection mechanisms proposed at EUROCRYPT 2020.

- State size: 4 limbs = 4× 128bits
- Round number: 24



(a) Round function of FRIET-P

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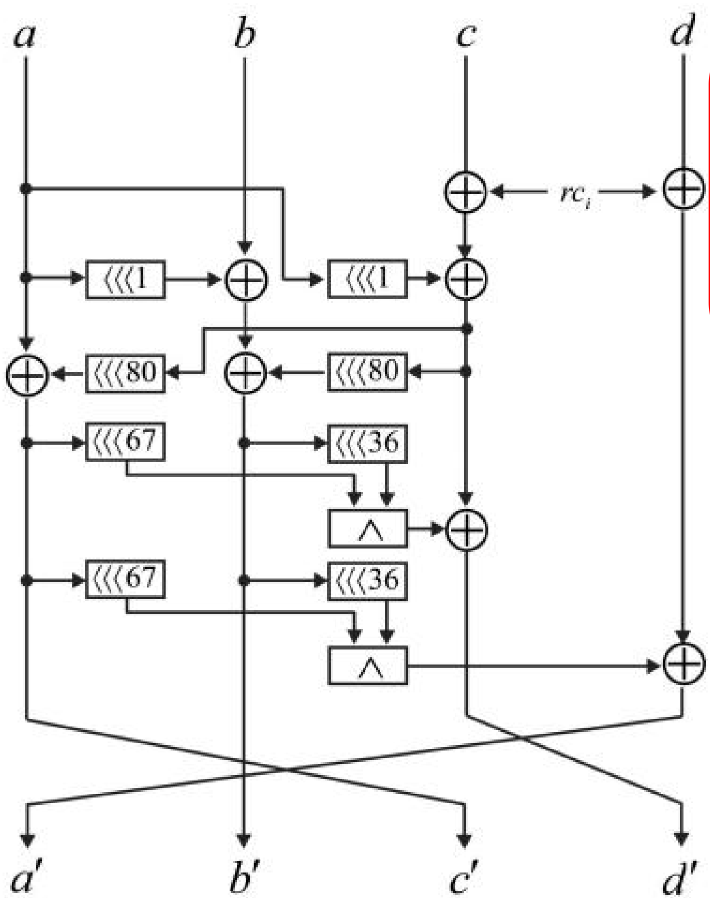

(a) Round function of FRIET-P

The round function of FRIET-P has slice-wise code-abiding property which means that $a \oplus b \oplus c = d$ implies $a' \oplus b' \oplus c' = d'$。

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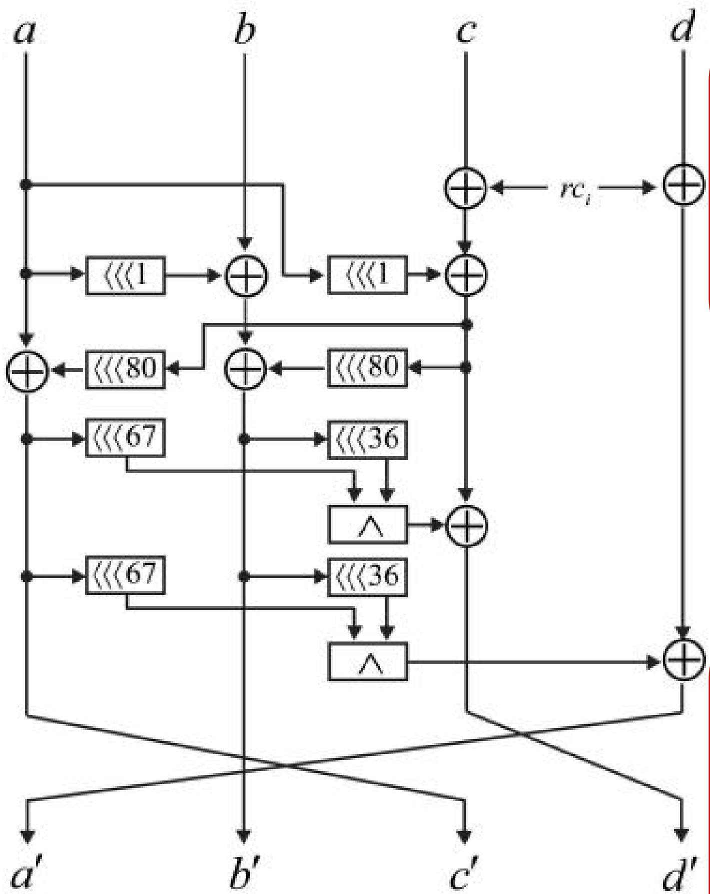

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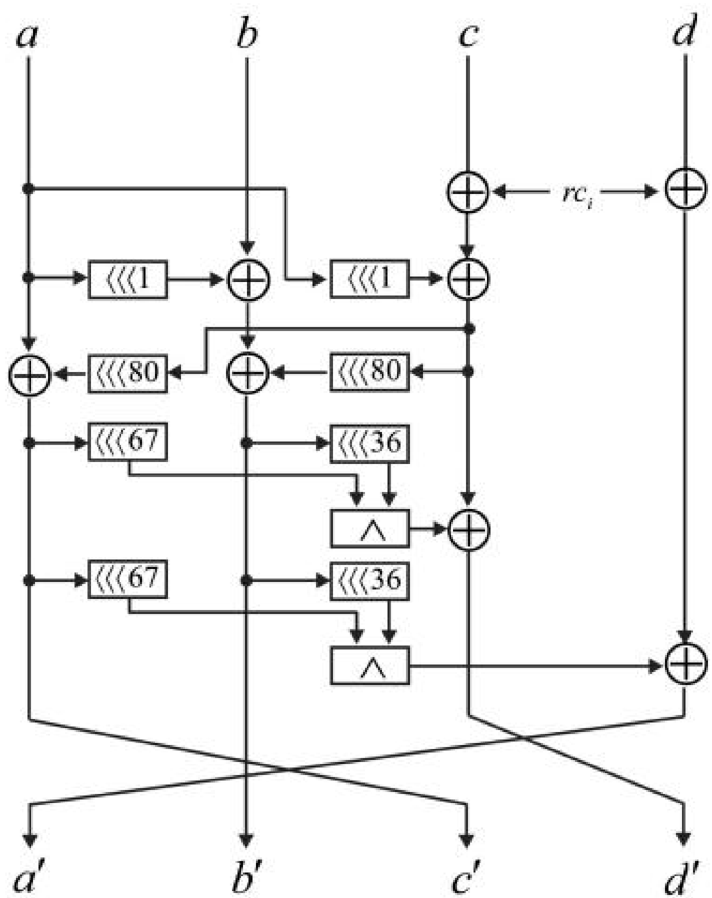
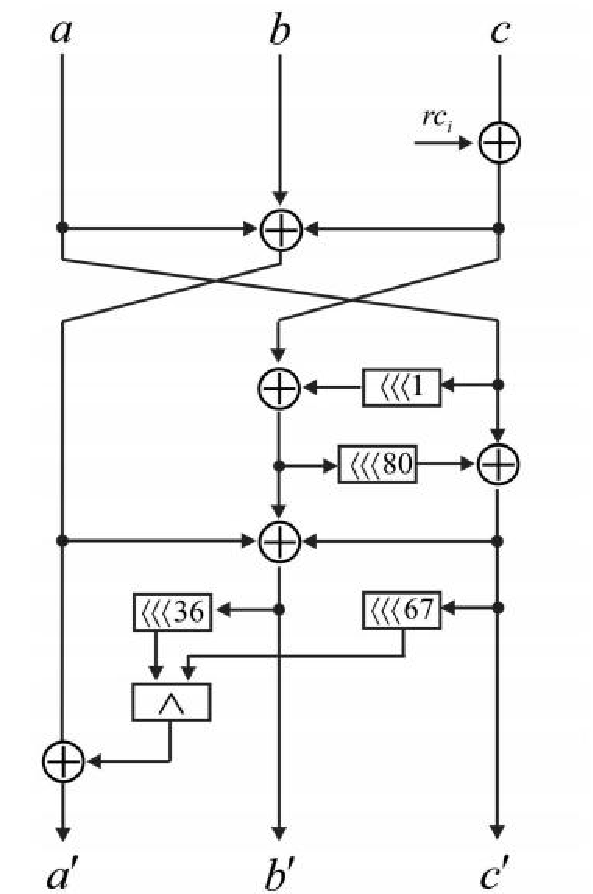
Faults will be detected if output does not have code–abiding property when the input state has code–abiding property.



(a) Round function of FRIET-P

ignore *d*



(b) Round function of FRIET-PC

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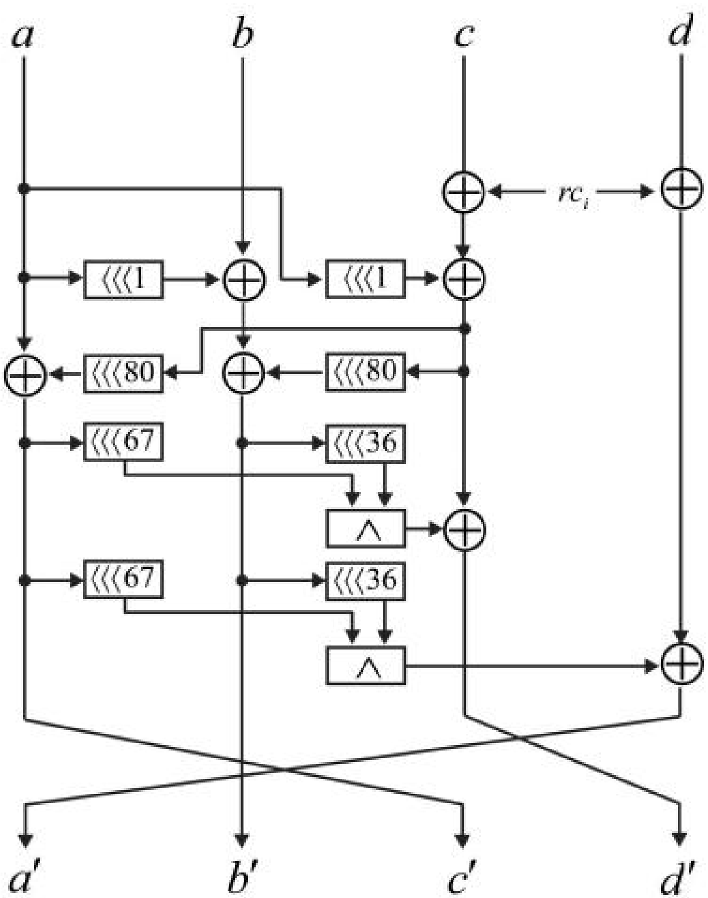

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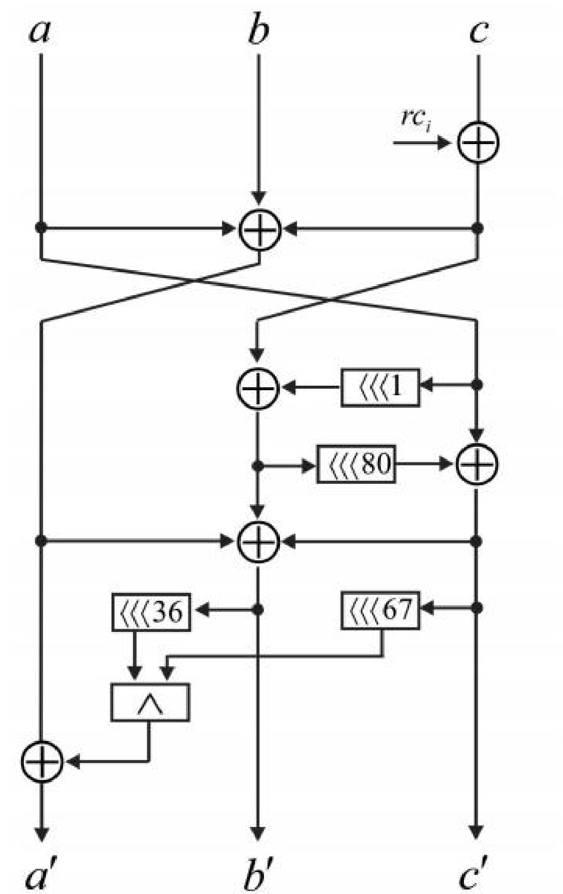

(b) Round function of FRIET-PC

Since a distinguisher for FRIET-PC directly translates to a distinguisher for FRIET-P, we focus on FRIET-PC.

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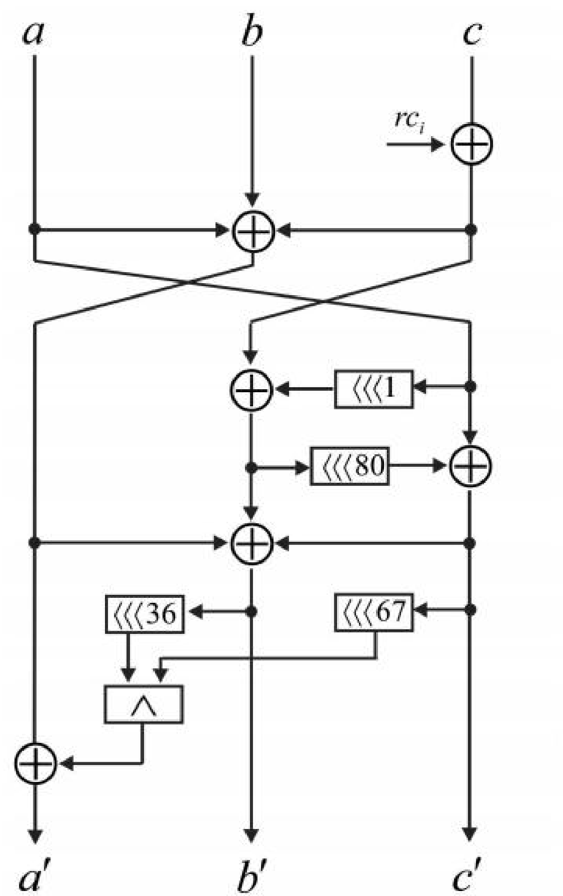

(b) Round function of FRIET-PC

- FRIET-PC only has four operations: Rotation, XOR, XOR-constant and AND. Bitwise AND is the only nonlinear operation.

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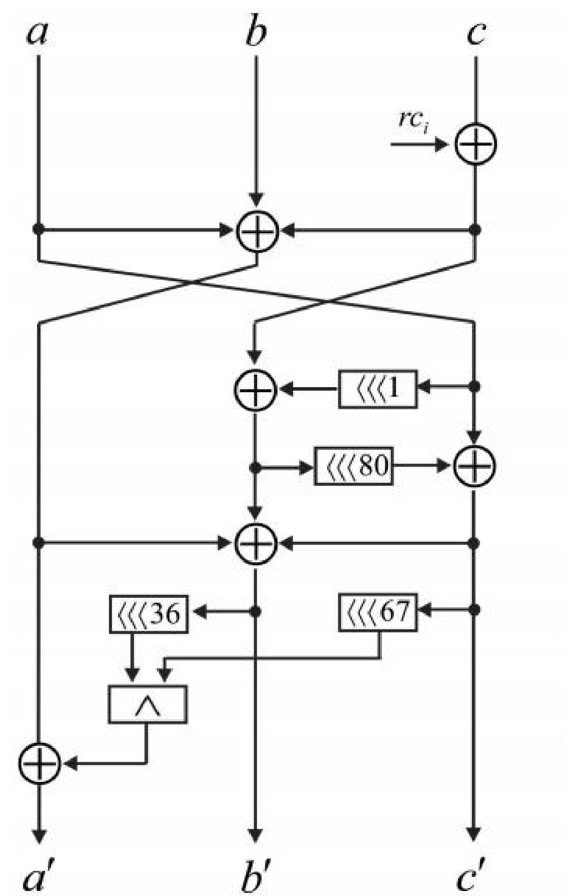

(b) Round function of FRIET-PC

- FRIET-PC only has four operations: Rotation, XOR, XOR-constant and AND. Bitwise AND is the only nonlinear operation.

- If we can effectively control the propagations of differences and linear masks through bitwise AND operation, we can obtain pair of differences with high probabilities and linear masks with high correlations.

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2. A Differential Distinguisher for Full-round FRIET-PC

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Differential Property 1 (AND) [SBD+20] Let $z = x \wedge y$ be an AND function. For the input difference $\alpha || \beta \in F_2^{2n}$ of $x || y$ and output difference $\gamma \in F_2^n$ of z. Then, the differential probability can be calculated as following.

$$Pr[\alpha || \beta \to \gamma] = \begin{cases} 2^{-wt(\alpha \vee \beta)}, & \text{if } \overline{\alpha} \wedge \overline{\beta} \wedge \gamma = \mathbf{0}_n, \\ 0, & \text{otherwise,} \end{cases}$$

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Thus, the differential probability of a valid pair of differences for bitwise AND operation is determined by $\boldsymbol{wt(\alpha \vee \beta)}$.

2. A Differential Distinguisher for Full-round FRIET-PC

- **By fixing the input difference of AND operation to 0, we have the following lemma.**

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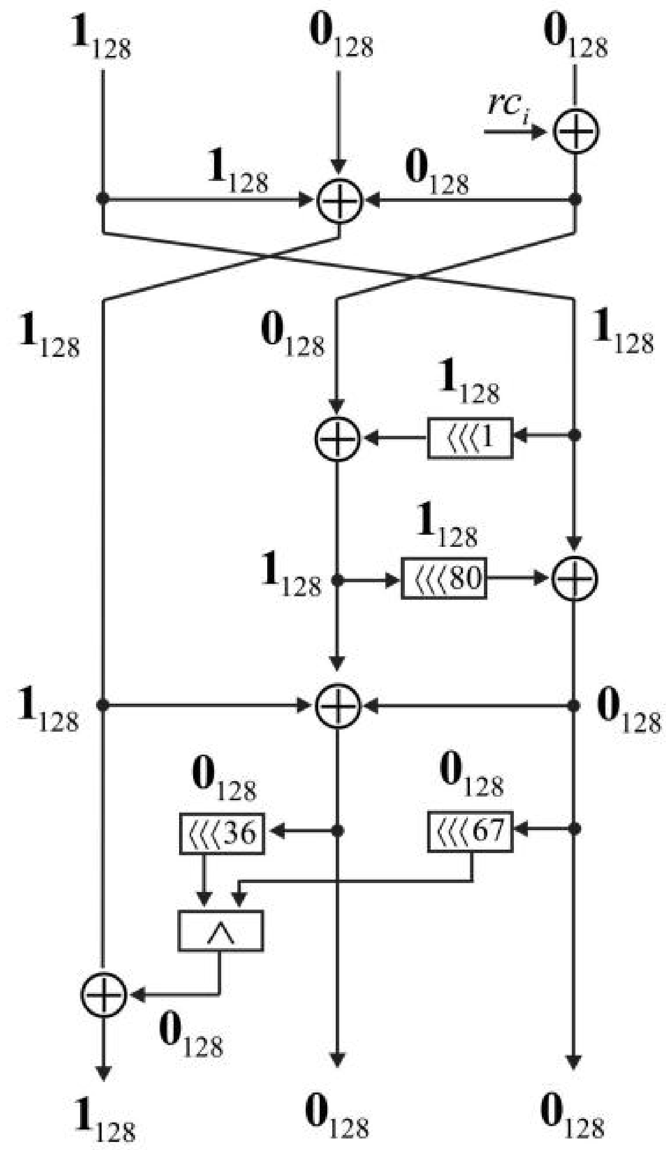
Lemma 1 The differential probability of difference $(\alpha, \beta, \gamma) \rightarrow (\alpha', \beta', \gamma')$ for the round function of FRIET-PC is 1 if and only if

$$\begin{cases} \alpha' = \alpha \oplus \beta \oplus \gamma, \\ \alpha \oplus (\alpha \lll 1) \oplus \beta = \mathbf{0}_{128}, \\ \alpha \oplus (\alpha \lll 81) \oplus (\gamma \lll 80) = \mathbf{0}_{128}, \\ \beta' = \mathbf{0}_{128}, \\ \gamma' = \mathbf{0}_{128}. \end{cases}$$

2. A Differential Distinguisher for Full-round FRIET-PC

Based on Lemma 1, for full-round FRIET-PC, we obtain a differential distinguisher with probability 1. In order to help readers understand the differential distinguisher better, we show the propagation of it through 1-round FRIET-PC in the right part.



(a) Differential distinguisher

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Linear Property 1 (AND) [SBD+20]. *Let $z = f(x, y)$ be an AND function, where $x \in \mathbb{F}_2^n$ and $y \in \mathbb{F}_2^n$ are the input variables, and the output variable z is calculated as $z = x \wedge y$. Then,*

$$Cor(\alpha||\beta, \gamma) = \begin{cases} 2^{-wt(\gamma)}, & \text{if } \gamma \vee (\overline{\alpha} \wedge \overline{\beta}) = \mathbf{1}_n, \\ 0, & \text{otherwise,} \end{cases}$$

where $\alpha||\beta \in \mathbb{F}_2^{2n}$ and $\gamma \in \mathbb{F}_2^n$ are the linear masks of $x||y$ and z, respectively.

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where $\alpha||\beta \in \mathbb{F}_2^{2n}$ and $\gamma \in \mathbb{F}_2^n$ are the linear masks of $x||y$ and z, respectively.

Thus, the linear correlation of a valid pair of linear masks for bitwise AND operations is determined by $wt(\gamma)$.

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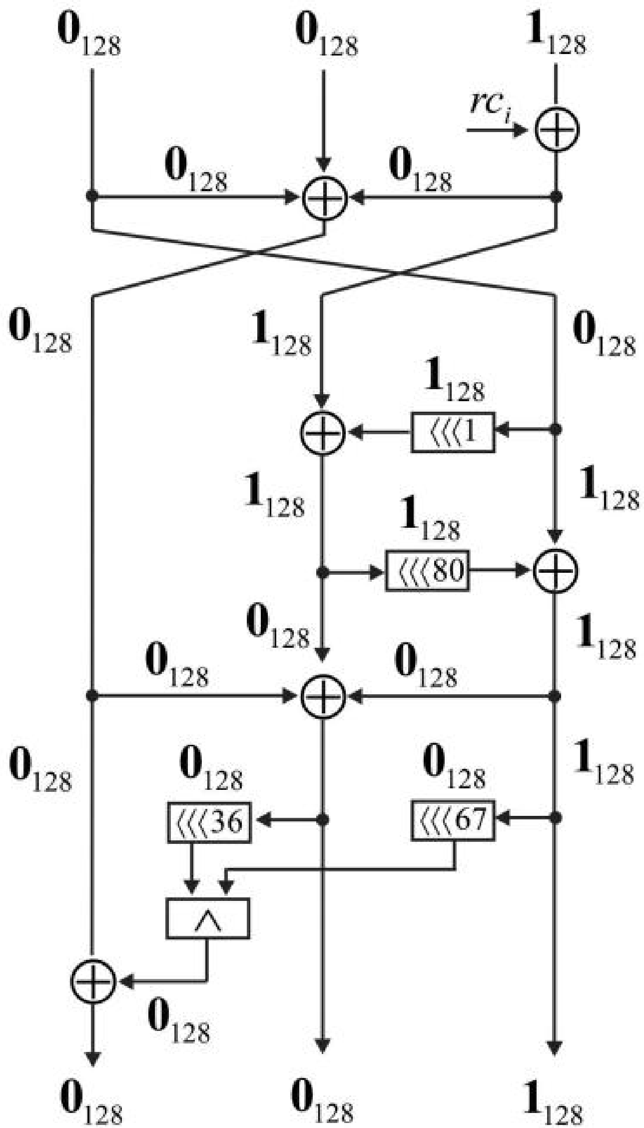
Lemma 3. *Let* $\Gamma_{in} = (\alpha, \beta, \gamma)$ *and* $\Gamma_{out} = (\alpha', \beta', \gamma')$ *be the input and output linear masks of the i-th round function* $(a', b', c') = FRIET\text{-}PC_i\,(a, b, c)$*. The absolute value of correlation* $Cor\,(\Gamma_{in}, \Gamma_{out})$ *is 1 if and only if*

$$\begin{cases} \alpha' = \mathbf{0}_{128}, \\ \alpha \oplus (\beta' \ggg 1) \oplus \gamma' \oplus ((\beta' \oplus \gamma') \ggg 81) = \mathbf{0}_{128}, \\ \beta \oplus \beta' = \mathbf{0}_{128}, \\ \gamma \oplus ((\beta' \oplus \gamma') \ggg 80) = \mathbf{0}_{128}. \end{cases} \tag{13}$$

3. A Linear Distinguisher for Full-round FRIET-PC

According to Lemma 3, we obtain a linear distinguisher for full-round FRIET-PC whose absolute value of correlation is 1. We show the propagation of it through 1-round FRIET-PC in the right part.



(b) Linear distinguisher

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4. Practical Attacks on Full-round FRIET-AE

When FRIET-P is used in authenticated encryption scheme, FRIET-AE is obtained.

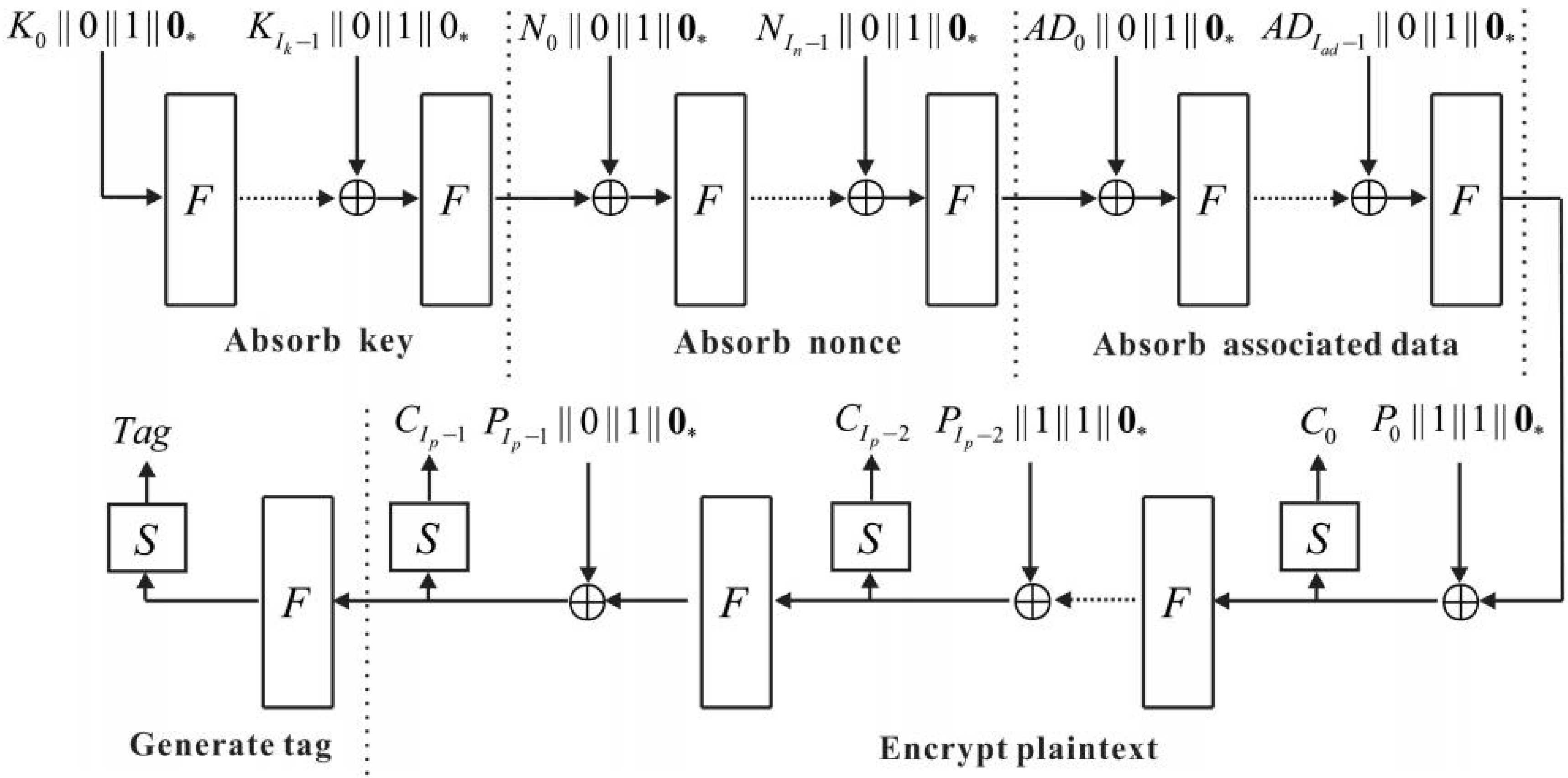
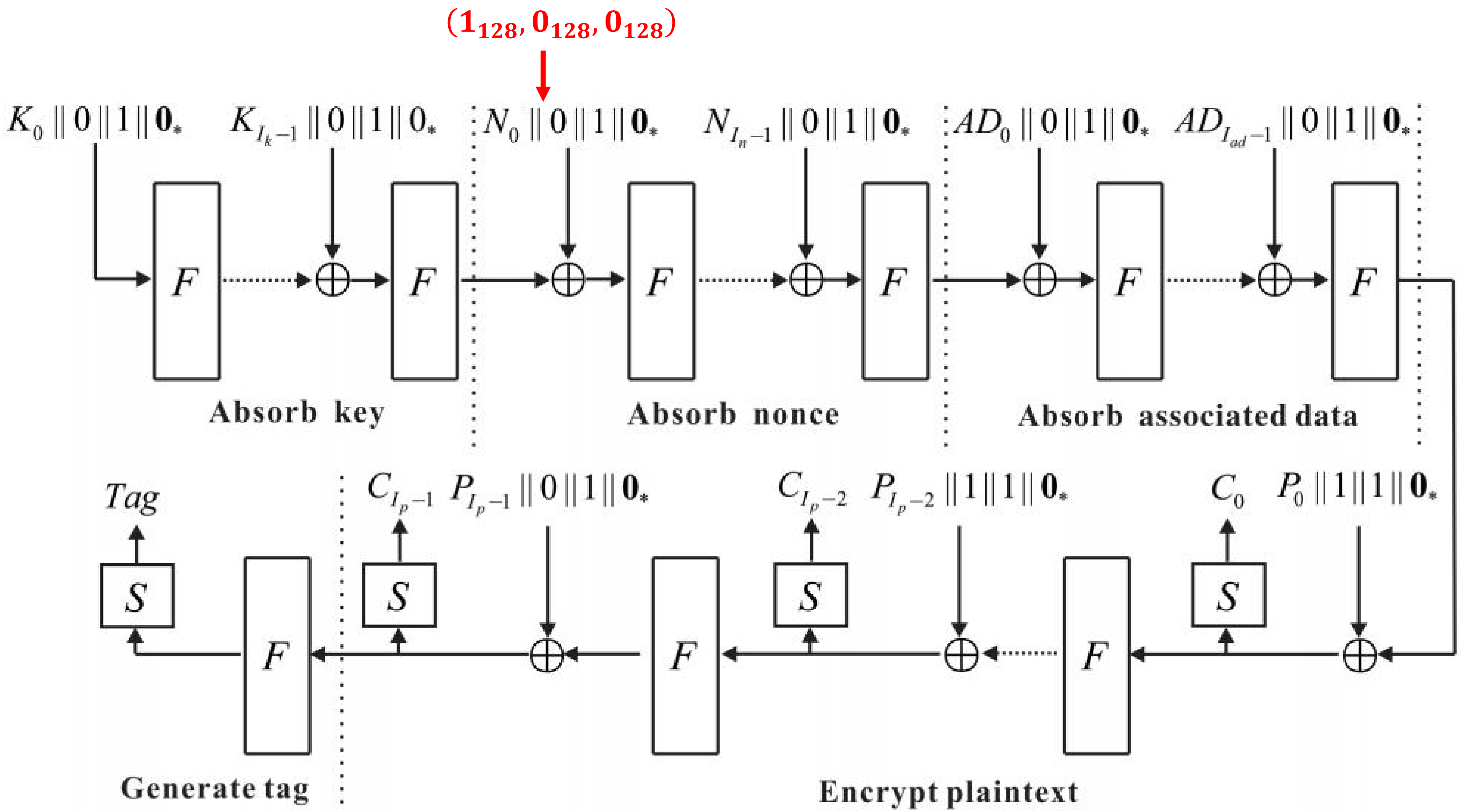


Figure 3: The encryption procedure of FRIET-AE [SBD+20]

4. Practical Attacks on Full-round FRIET-AE

Because the differential probabilities of $(1_{128}, 0_{128}, 0_{128}) \rightarrow (1_{128}, 0_{128}, 0_{128})$ over the full-round FRIET-PC are 1. Thus, we can introduce difference into key, nonce, associate data, and plaintext.



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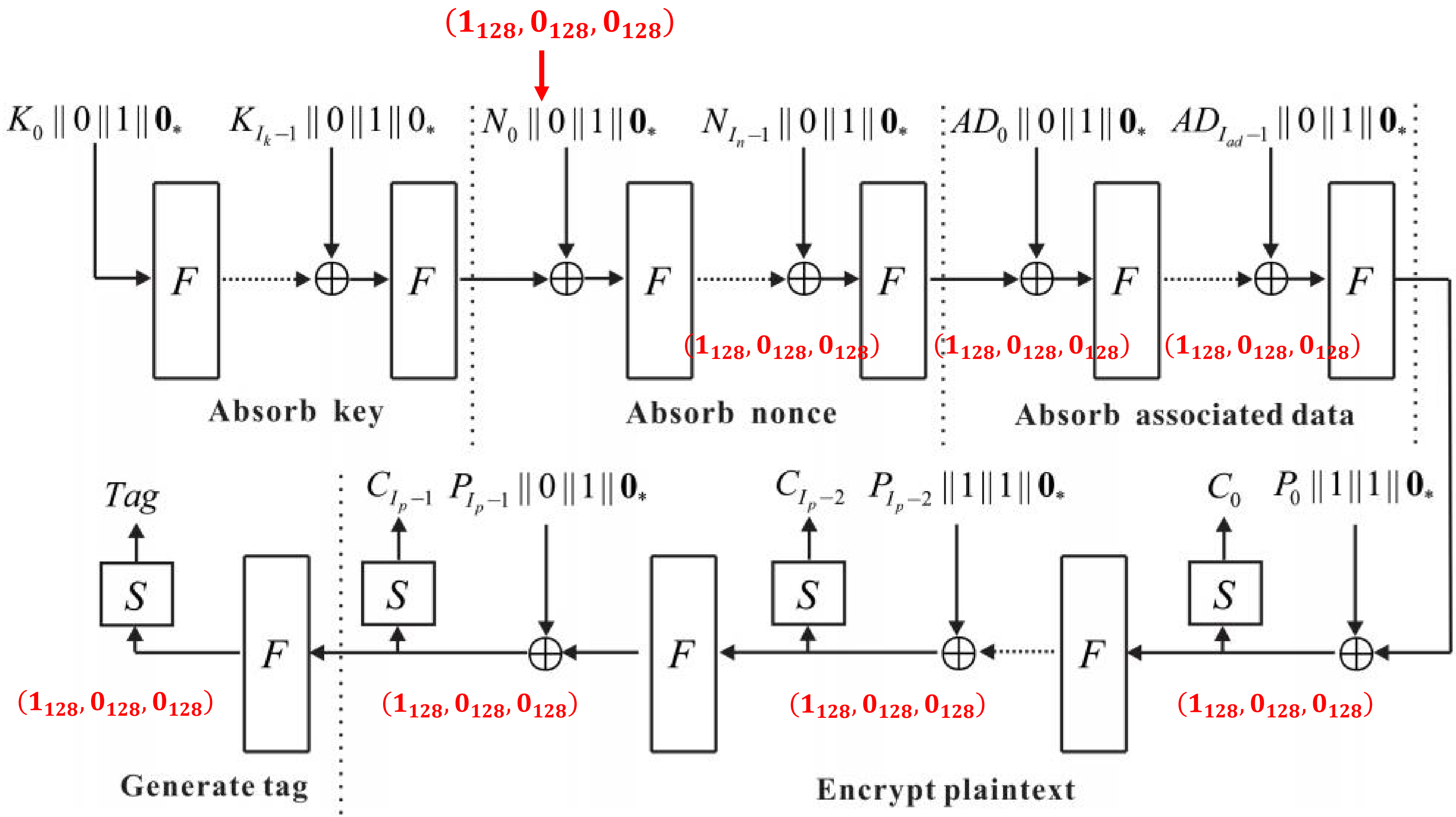

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Conclusions

- Differential and linear distinguishers for the full-round FRIET-PC are proposed.

Table 1: The comparison of the distinguishers for FRIET-PC

*Type	Round	†Probability/Correlation/Data	Reference
LC	7	2^{-29}	[SBD+20]
	8	2^{-40}	[SBD+20]
	$^*R$	1 or -1	Sect. 3.1
R-DL	8	$2^{-17.81}$	[LSL21]
	9	$2^{-29.81}$	[LSL21]
	13	$2^{-117.81}$	[LSL21]
IC	13	2^{-31}	[ISS+21]
	15	2^{-63}	[ISS+21]
	17	2^{-127}	[ISS+21]
	30	2^{-383}	[ISS+21]
DC	6	2^{-59}	[SBD+20]
	9	$2^{-20.04}$	[ISS+21]
	$^*R$	1	Sect. 3.2

⋆ R-DL denotes rotational differential-linear distinguisher. LC denotes linear distinguisher. DC denotes differential distinguisher. IC denotes integral distinguisher.

† The DC is showed with probability. LC/DL/R-DL are showed with correlation. IC is showed with data.

* R means that the differential or linear distinguisher is valid for any-round FRIET-PC.

Conclusions

- Differential and linear distinguishers for the full-round FRIET-PC are proposed.
- Using the differential distinguisher with probability 1, we propose an algorithm which can generate a set consisting of valid tags and ciphertexts which are not created by legal users. This breaks the integrity and confidentiality security claims of FRIET-AE.

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Future Works

- Our attack in this paper does not recover the secret key of FRIET-AE. How to give a key-recovery attack needs further research

Thanks