Cryptanalysis of AES-PRF and Its Dual

Patrick Derbez[1] Tetsu Iwata[2] Ling Sun[3,4] Siwei Sun[5]
Yosuke Todo[6] Haoyang Wang[4] Meiqin Wang[3]

1. Univ Rennes, CNRS, IRISA, France
2. Nagoya University, Japan
3. Shandong University, China
4. Nanyang Technological University, Singapore
5. Chinese Academy of Sciences, China
6. NTT Secure Platform Laboratories, Japan

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Overview

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4. **Attacks on AES-PRF**
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Background and Motivation

Background

Pseudorandom permutation (PRP)

- Main primitives in symmetric-key cryptography
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PRP-to-PRF conversion

- Large efficiency costs design, e.g., Truncation, XOR of Permutations (XoP), Encrypted Davies-Meyer (EDM), The Dual of EDM (EDMD)
- Dedicated design with small efficiency costs, e.g., FastPRF,

$$\mathrm{FastPRF}_K(X) = E_K(X) \oplus E_K^1(X).$$

Motivation

Observations

- $\text{AES-PRF}_{s,t}$ is as efficient as AES
- Efficiency and cost-effectiveness comes at the cost of provable security
- Provable security result of EDMD no longer applies to AES-PRF

Open Problems

- $(s, t) = (2, 8)$ is left as an open question
- The security of $\text{AES-PRF}_{s,t}$
- The security of the dual version (Dual-AES-PRF)

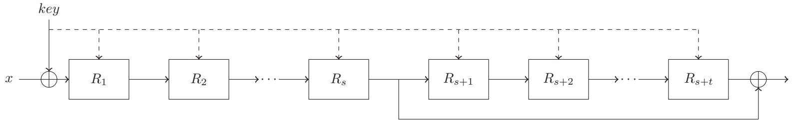
Methods

- ID, ZC, DC, and MITM

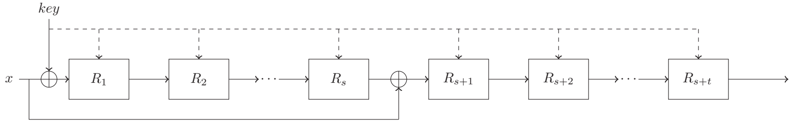
Preliminary

AES-PRF & Dual-AES-PRF

- AES-PRF$_{s,t}$ (Mennink and Neves @ FSE 2018)



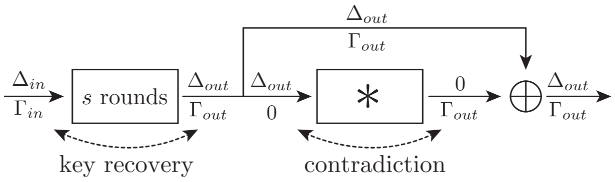
- Dual-AES-PRF$_{s,t}$



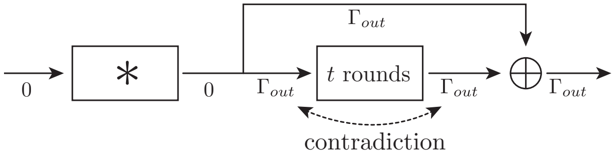
Overview of Our Attacks

Attacks on AES-PRF

Impossible differential/Zero-correlation attacks ($s \leqslant 2$)



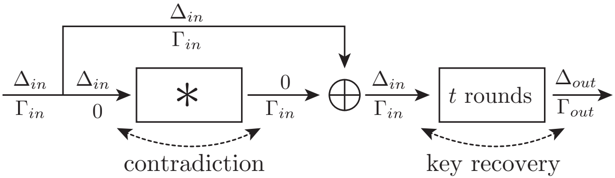
Zero-correlation distinguishers ($t \leqslant 4$)



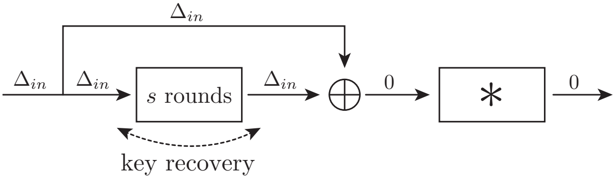
Meet-in-the-middle attacks on AES-PRF$_{s,7-s}$

Attacks on Dual-AES-PRF

Impossible differential/Zero-correlation attacks ($t \leqslant 2$)

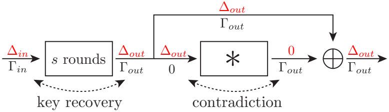


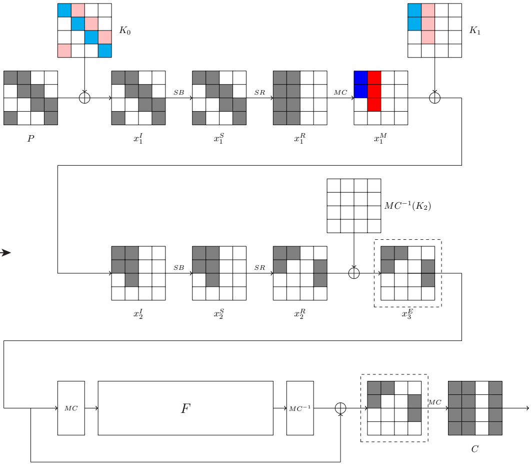
Differential attacks ($s \leqslant 4$)



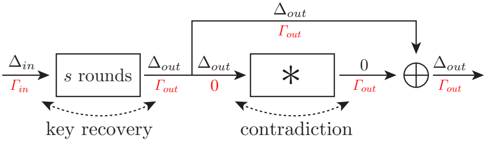
Attacks on AES-PRF

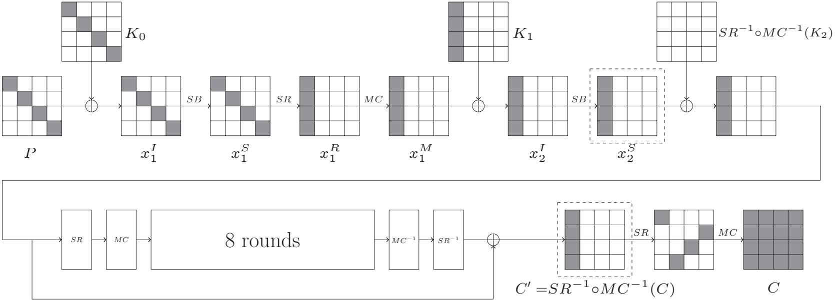
Impossible Differential Attack for AES-PRF$_{2,8}$



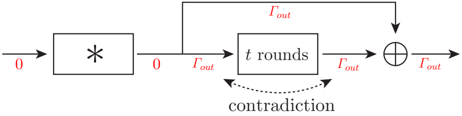


Zero-Correlation Linear Attack for AES-PRF$_{2,8}$

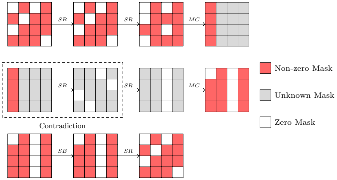




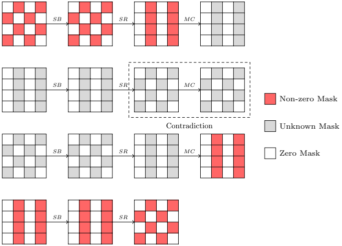
Distinguishers against AES-PRF$_{7,3}$ & AES-PRF$_{6,4}$



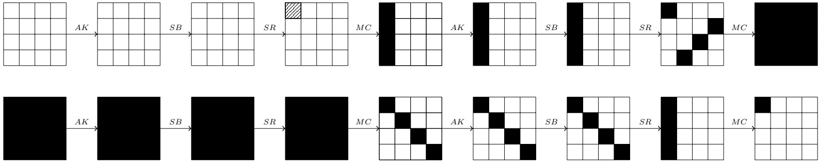
ZC Distinguisher for AES$_3$



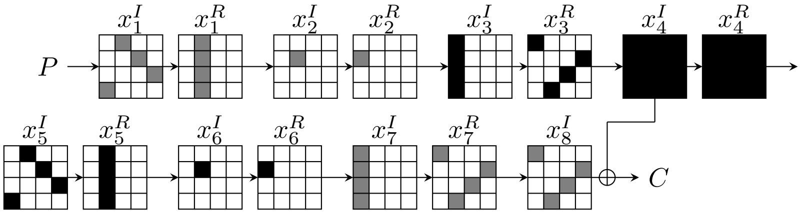
ZC Distinguisher for AES$_4$



Attack against AES-PRF$_{3,4}$

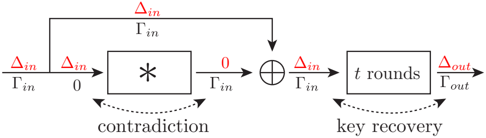


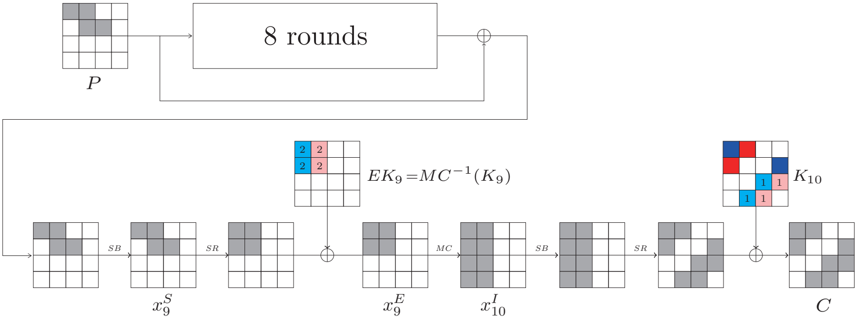
- The number of possible sequences: $(2^8)^{255} = 2^{2040} \longrightarrow (2^8)^{25} = 2^{200}$



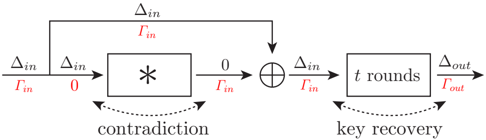
Attacks on Dual-AES-PRF

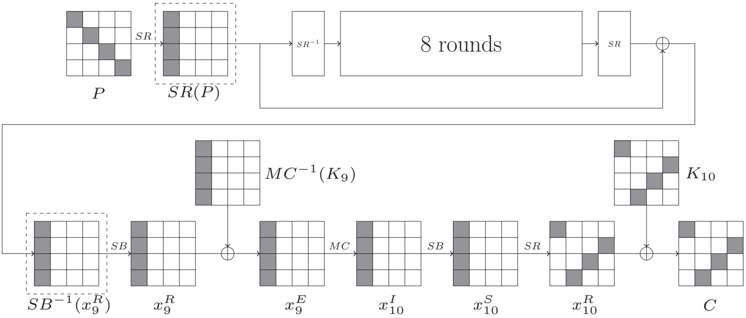
Impossible Differential Attack for Dual-AES-PRF$_{2,8}$



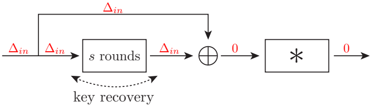


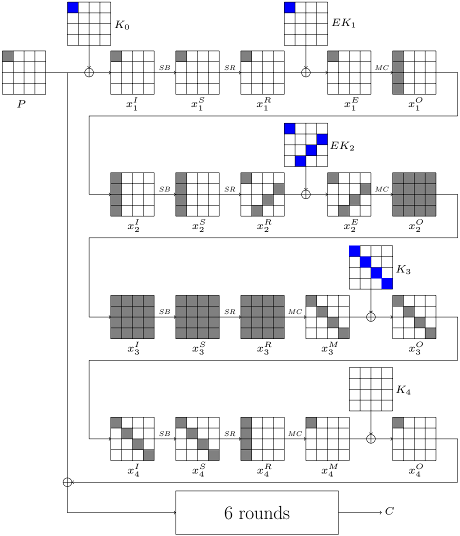
Zero-correlation attack for Dual-AES-PRF$_{8,2}$





Differential Attack for Dual-AES-PRF$_{4,6}$





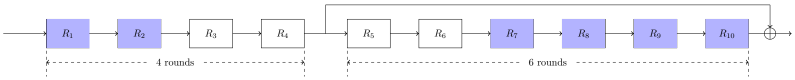
Summary and Conclusion

Summary

Target	s	t	Time	Data	Memory	Method	Ref
AES-PRF	1	*	2^{101}	2^{67} CP	2^{67}	ID	@FSE 2017
	*	1	–	–	–	Statistics	
AES-PRF	1	*	2^{71}	2^{71} CP	2^{64}	ID	Our Results
	1	*	$2^{122.49}$	$2^{103.34}$ KP	2^{96}	ZC	
	2	*	2^{94}	2^{94} CP	2^{88}	ID	
	2	*	$2^{115.14}$	$2^{115.06}$ KP	2^{65}	ZC	
	*	3	$2^{84.96}$	$2^{84.96}$ KP	$2^{84.96}$	ZC distinguisher	
	*	4	$2^{96.95}$	$2^{96.95}$ KP	2^{64}	ZC distinguisher	
	s	$7-s$	2^{107}	2^{107} CP	2^{104}	MitM	
Dual-AES-PRF	*	1	2^{71}	2^{71} CP	2^{64}	ID	Our Results
	*	1	$2^{122.49}$	$2^{103.34}$ KP	2^{96}	ZC	
	*	2	2^{104}	2^{104} CP	2^{72}	ID	
	*	2	$2^{115.14}$	$2^{115.06}$ KP	2^{65}	ZC	
	3	*	2^{97}	2^{97} CP	2^{32}	Differential	
	4	*	2^{121}	2^{121} CP	2^{8}	Differential	

Conclusion

- Comparison between AES-PRF and Dual-AES-PRF
  - The security of AES-PRF is **higher** than Dual-AES-PRF from the applicability of differential attacks.
  - Both AES-PRF and Dual-AES-PRF **have only one** round as the security margin.
- Choice of the parameter
  - The balanced case AES-PRF$_{5,5}$ is certainly a natural choice of the design.
  - However, our results indicate that $(s, t) = (4, 6)$ for AES-PRF is potential to be more secure, since the margin with respect to the attacked rounds becomes larger.



Thank you for your attention!

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