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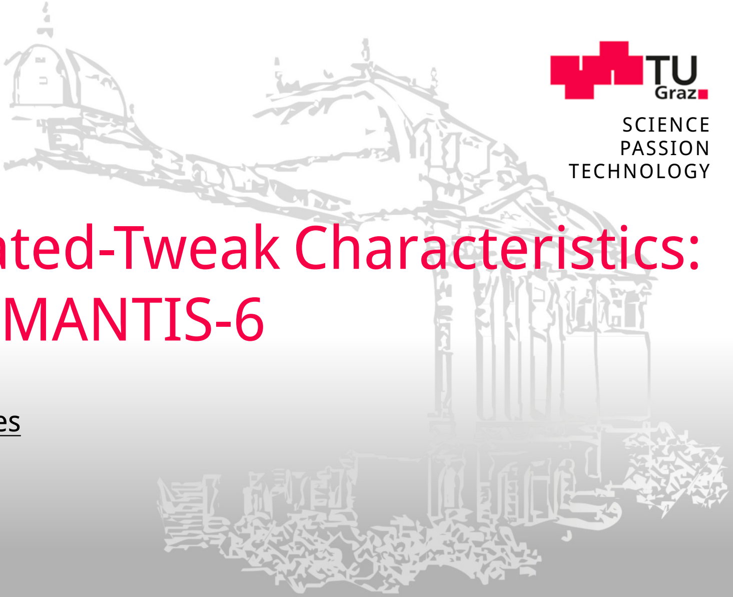


Clustering Related-Tweak Characteristics: Application to MANTIS-6

Maria Eichlseder   Daniel Kales

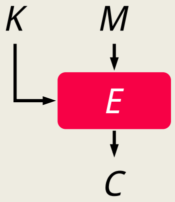
Paris, March 27th, 2019

Overview

- Context, target cipher `MANTIS`
- Differential attack strategy
- Probability Calculation for Clustered Differentials
- Experiments

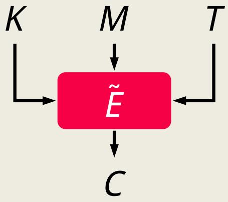
Primitive: Tweakable Block Cipher

Block Ciphers



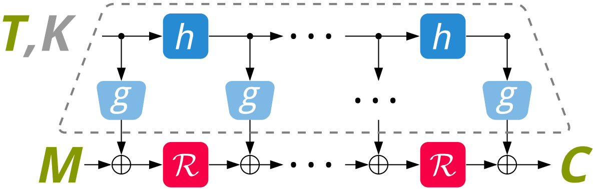
AES, DES, ...

Tweakable Block Ciphers



Skinny, MANTIS, QARMA, ...

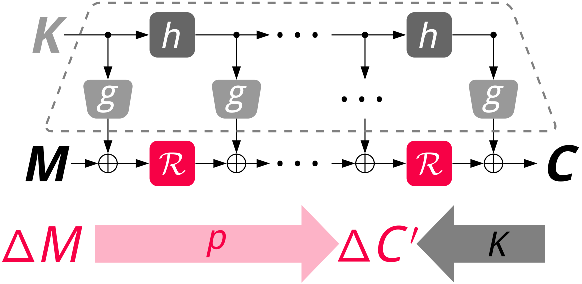
The TWEAKEY/STK framework [JNP14]



Cryptanalytically interesting properties:

- Linear tweak schedule
- Attacker controls tweak → related-tweak attacks

Differential Cryptanalysis [BS90]



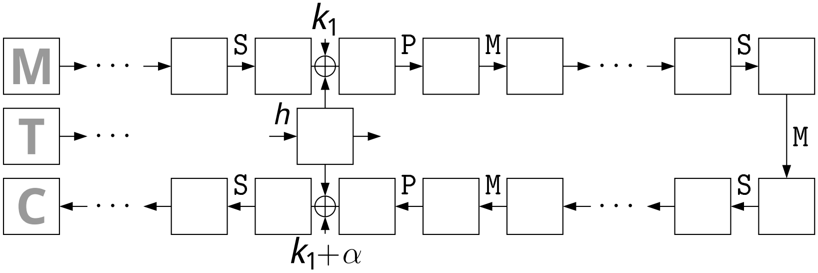
MANTIS

- CRYPTO 2016 [BJK+16]: Tweakable block cipher with low latency
- MANTIS-5 (12 rounds), MANTIS-7 (16 rounds)

MANTIS

CRYPTO 2016 [BJK+16]: Tweakable block cipher with low latency

MANTIS-5 (12 rounds), MANTIS-7 (16 rounds)

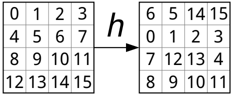


`MANTIS` – Round function $\mathcal{R}_i$

- `S` `SubCells`: involutive 4-bit S-box $\mathcal{S}$
- `A` `AddTweakey`$_i$, `AddConstant`$_i$: Xor key k_1 (for $\mathcal{R}_i$) or $k_1 + \alpha$ (for $\mathcal{R}_i^{-1}$), permuted tweak $h^i(T)$, and round constant C_i
- `P` `PermuteCells`: fast permutation of state cells
- `M` `MixColumns`: involutive near-MDS matrix `M` over $\mathbb{F}_{2^4}$

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

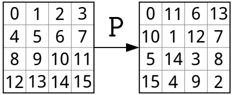
(a) S-box



0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

6	5	14	15
0	1	2	3
7	12	13	4
8	9	10	11

(b) Tweak schedule



0	1	2	3
4	5	6	7
8	9	10	11
12	13	14	15

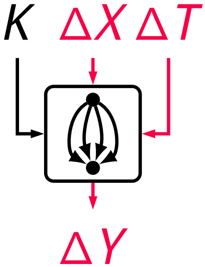
0	11	6	13
10	1	12	7
5	14	3	8
15	4	9	2

(c) `PermuteCells`

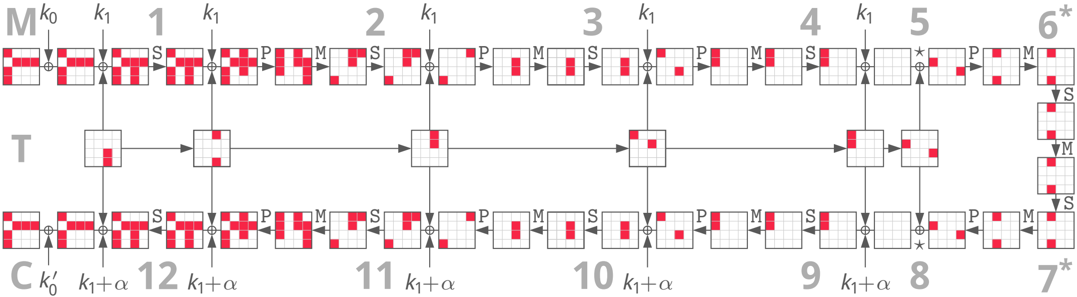
$$\mathtt{M} = \begin{pmatrix} 0 & 1 & 1 & 1 \\ 1 & 0 & 1 & 1 \\ 1 & 1 & 0 & 1 \\ 1 & 1 & 1 & 0 \end{pmatrix}$$

(d) `MixColumns`

Attack strategy



Previous strategy for MANTIS-5, FSE 2017 [DEKM16]



🟥 $1 = |\chi_i|$ Differential characteristic 2^{-72}

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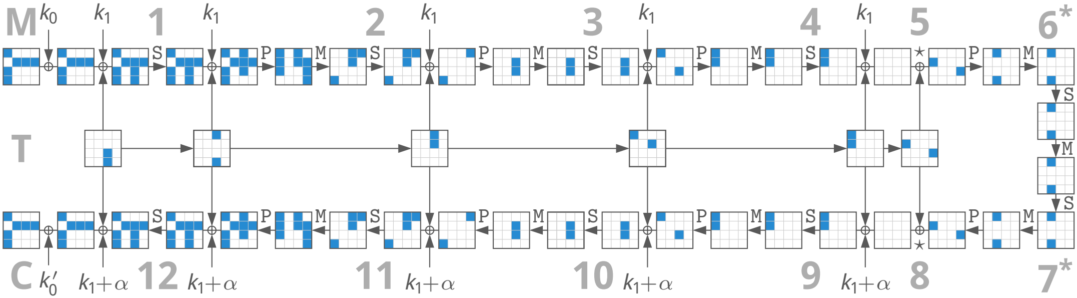

🟥 $1 = |\chi_i|$ Differential characteristic 2^{-72}

🟦 15 or 16 Truncated differential characteristic 2^{-100}

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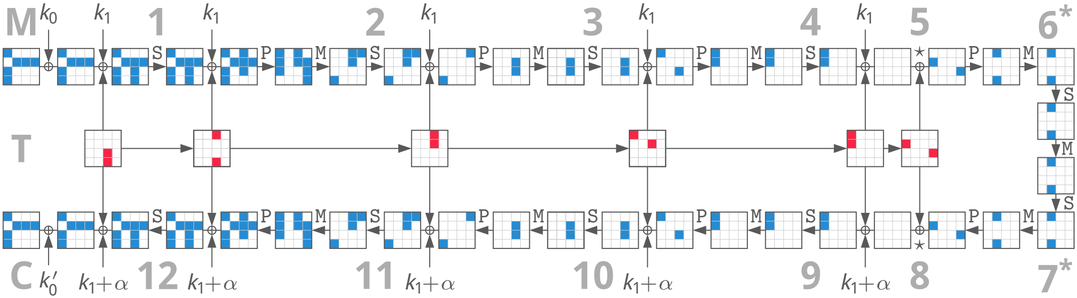

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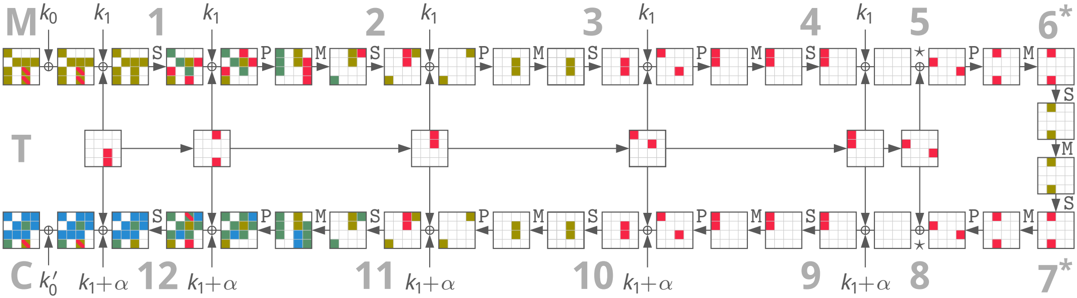

🟥	$1 = \lvert\chi_i\rvert$	Differential characteristic	2^{-72}
🟨	4	This cluster	2^{-39}
🟩	13		
🟦	15 or 16	Truncated differential characteristic	2^{-100}

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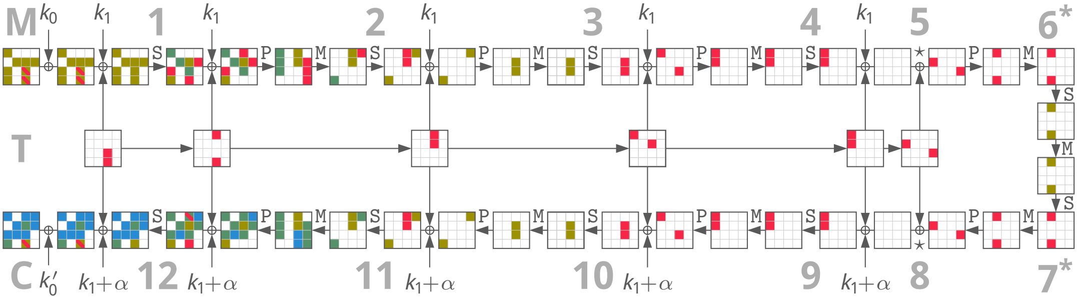
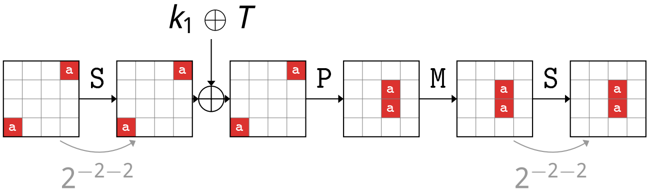


🟥	$1 = \lvert\chi_i\rvert$	Differential characteristic	2^{-72}
🟨	4	This cluster	2^{-39}
🟩	13	Data complexity per solution	$2^{\approx 25}$
🟦	15 or 16	Truncated differential characteristic	2^{-100}

Probability of Differential Clusters

Probability of Differential Clusters



🟥 $\chi_i = \{\mathtt{a}\}$

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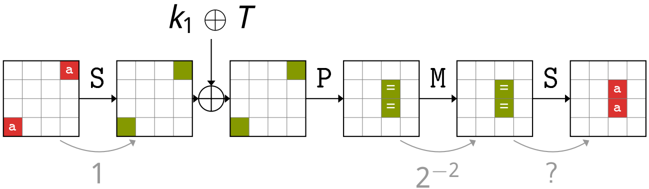

🟥 $\chi_i = \{\mathtt{a}\}$

🟩 $\chi_i = \sigma(\{\mathtt{a}\})$
$= \{\mathtt{a}, \mathtt{f}, \mathtt{d}, \mathtt{5}\}$

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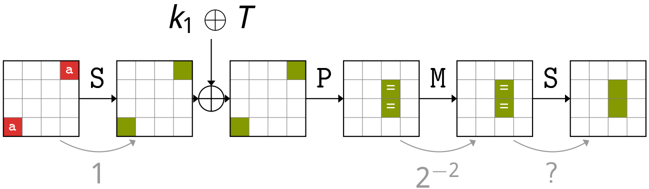

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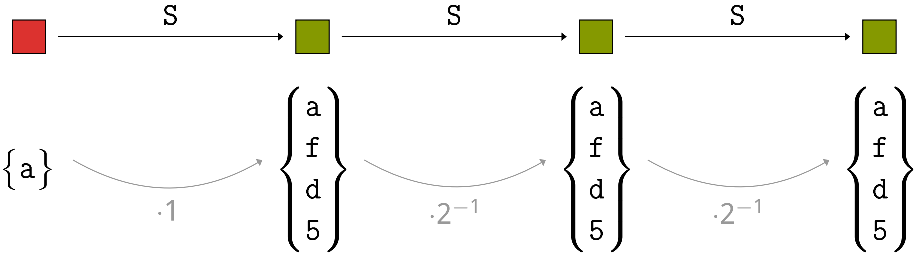
Probability of Differential Clusters

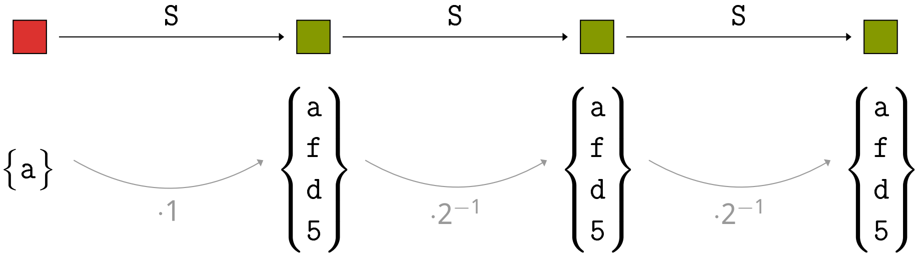
Compute transition probability based on DDT [DEKM16]



Probability of Differential Clusters

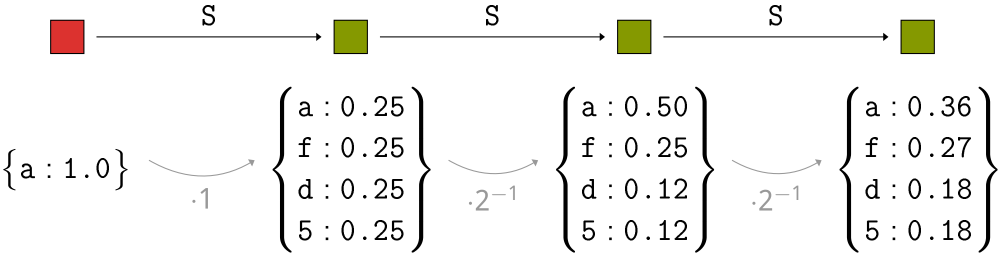
Compute transition probability based on DDT [DEKM16]

Assumes uniform distribution of differences!



Probability of Differential Clusters

Extend calulation with probability distribution.



S S S

$$\{a : 1.0\} \xrightarrow{\cdot 1} \left\{\begin{array}{l} a : 0.25 \\ f : 0.25 \\ d : 0.25 \\ 5 : 0.25 \end{array}\right\} \xrightarrow{\cdot 2^{-1}} \left\{\begin{array}{l} a : 0.50 \\ f : 0.25 \\ d : 0.12 \\ 5 : 0.12 \end{array}\right\} \xrightarrow{\cdot 2^{-1}} \left\{\begin{array}{l} a : 0.36 \\ f : 0.27 \\ d : 0.18 \\ 5 : 0.18 \end{array}\right\}$$

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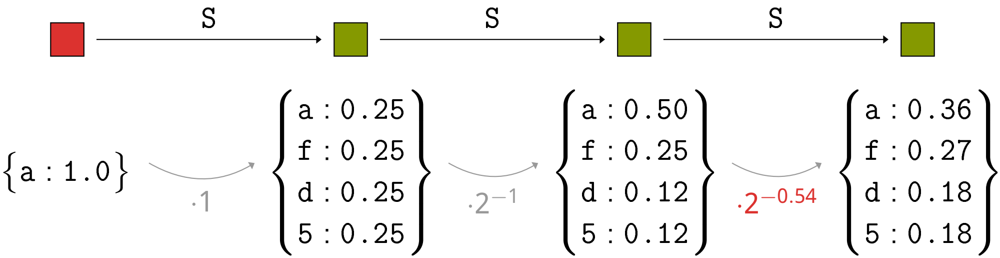

$$\{a:1.0\} \xrightarrow{\cdot 1} \left\{\begin{matrix} a:0.25 \\ f:0.25 \\ d:0.25 \\ 5:0.25 \end{matrix}\right\} \xrightarrow{\cdot 2^{-1}} \left\{\begin{matrix} a:0.50 \\ f:0.25 \\ d:0.12 \\ 5:0.12 \end{matrix}\right\} \xrightarrow{\cdot 2^{-0.54}} \left\{\begin{matrix} a:0.36 \\ f:0.27 \\ d:0.18 \\ 5:0.18 \end{matrix}\right\}$$

Automated Search for Differential Clusters

- Multi-step process (automated by toolchain)

1. Search for promising truncated characteristic (MILP/SAT/. . .)
2. Fix a promising tweak difference
3. Propagate constraints throughout the cipher
    - cell-wise for `S`, `A`, `P`
    - column-wise for `M`
4. Calculate probability and data-complexity

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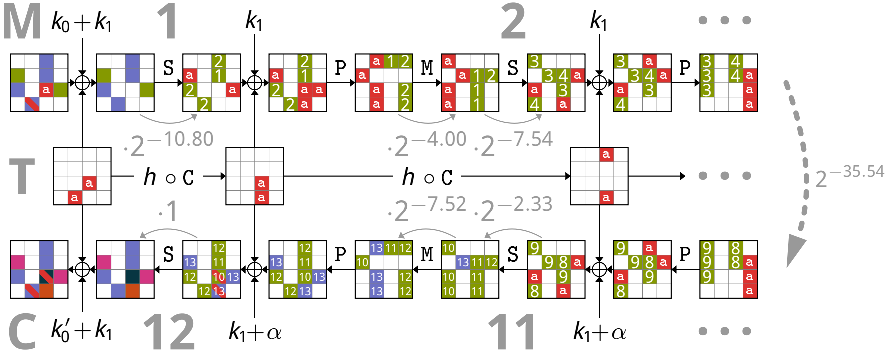
https://github.com/dkales/clusterfk

Key-Recovery Attack on $\texttt{MANTIS}_6$



🟥 $\Delta = \texttt{a}$ 🟩 $\Delta \in \sigma(\{\texttt{a}\}) = \{\texttt{a}, \texttt{f}, \texttt{d}, \texttt{5}\}$ 🟦 $\Delta \in \sigma(\{\texttt{a}, \texttt{f}, \texttt{d}, \texttt{5}\})$ 🟧 ⬛ 🟪 $\cdots$

- Average probability of cluster $\chi^M \to \chi^C$: $2^{-67.73}$ (data: $2^{46.73}$ per solution)
- Attack complexity (data × time): $2^{55.1} \times 2^{55.5} = 2^{110.6} \ll 2^{126}$

Key-Recovery Attack on $\mathtt{MANTIS}_6$

- Complex multi-phase key-recovery attack
  - Guess parts of first round key & apply filter
  - Guess parts of last round key & apply filter
  - Guess parts of combined round 2,11 key & apply filter
  - Intersect key guesses from multiple iterations

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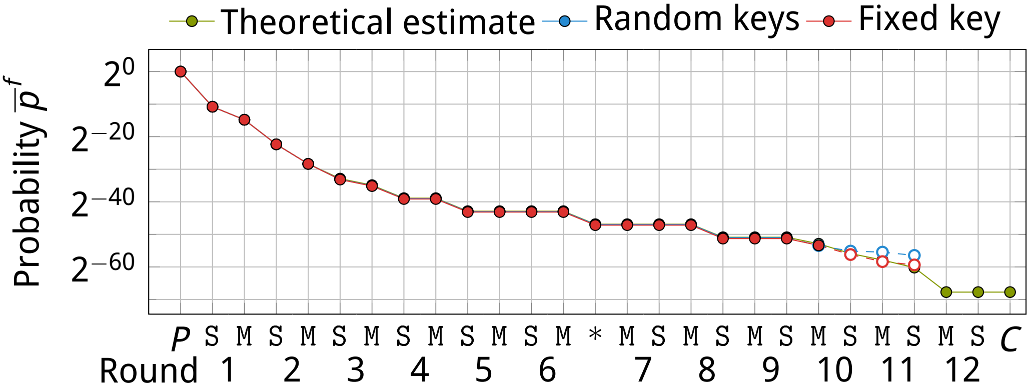
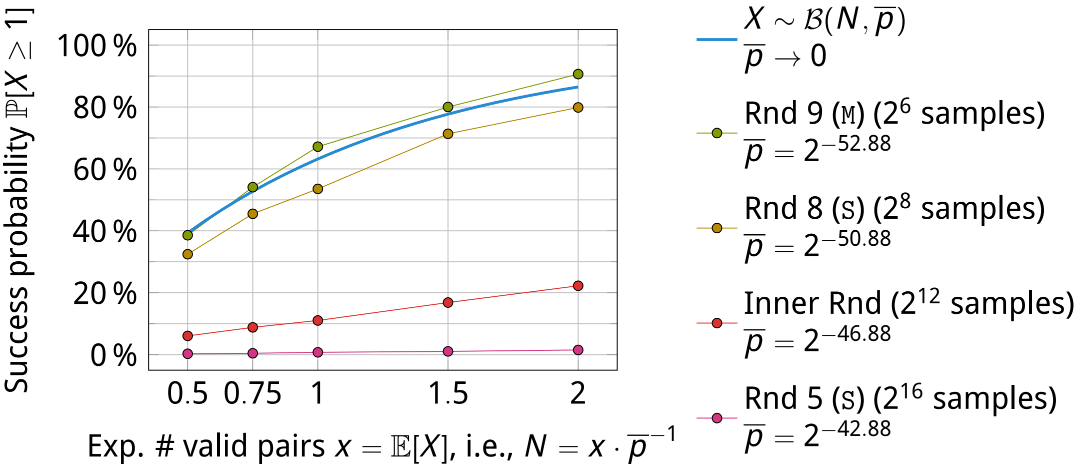
  - Intersect key guesses from multiple iterations
- Improved probability calculation used to calculate filter probability
  - compute backward, starting from the ciphertext

Experiments

Experiments – Probability of the characteristic



Experiments – Attack success probability $\mathbb{P}[X \geq 1]$



Conclusions

- Clustered related-tweak differentials
  - General method to find and evaluate clusters
  - Improved probability calculation for clusters
- New attack on $\texttt{MANTIS}_6$
- Extensive experiments to verify validity

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