PRESENT Cipher

Walkie Talkie

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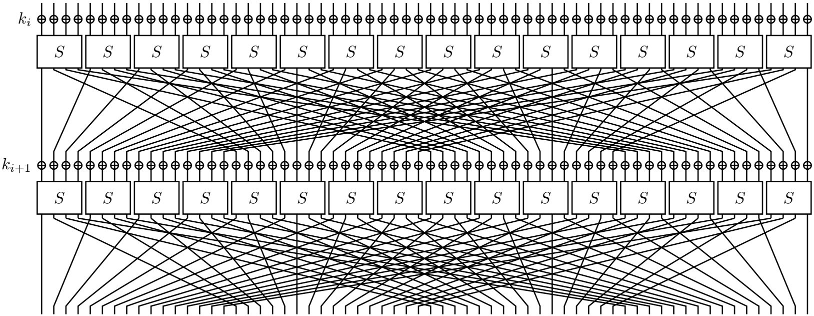
Outline

1. Introduction
2. Cipher Specifications
3. DC
4. Linear Cryptanalysis
5. Integral property
6. Brownie Point Nominations
7. Conclusion

The Present Cipher

- Ultra-Lightweight block cipher.
- Developed by the Orange Labs (France), Ruhr University Bochum (Germany) and the Technical University of Denmark in 2007.
- Supports 64 bits block size and 80 or 128 bits key sizes with 31 rounds.
- Designed to be used in micro-controllers and hardware where high chip performance and low power consumption are required.

Substitution / Permutation



x	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
$S[x]$	C	5	6	B	9	0	A	D	3	E	F	8	4	7	1	2

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Cipher Design

- PRESENT-80 is an example of SP-network.
- 4-bit S-Box is applied 16 times in parallel for the 64-bit input during each round.

High level psuedo-code of PRESENT algorithm

generateRoundKeys()
for $i = 1$ **to** 31 **do**
    addRoundKey($\textsc{State}$,K_i)
    sBoxLayer($\textsc{State}$)
    pLayer($\textsc{State}$)
addRoundKey($\textsc{State}$,K_{32})

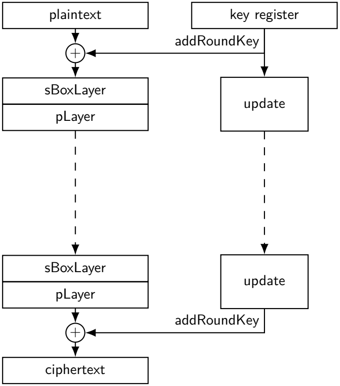
Cipher Design contd.

Add Round Key

- Round key $K_i = k_{63}, k_{62} \ldots k_0$ for $1 \leq i \leq 32$.
- Current state $S = s_{63}, s_{62} \ldots s_0$.

$$S \rightarrow S \oplus K_i$$
$$\Longrightarrow \; s_t \rightarrow s_t \oplus k_t$$

for $0 \leq t \leq 63$



Substitution Layer

Denote Fourier coefficient of S-Box.

$$S_b^W(a) = \sum_{x \in \mathbb{F}_2^4} (-1)^{\langle b, S(x)\rangle + \langle a, x\rangle} \tag{1}$$

PRESENT S-Box satisfies the following conditions.

- For any fixed input difference $\Delta_I \in \mathbb{F}_2^4, \Delta_I \neq 0$ and output difference $\Delta_O \in \mathbb{F}_2^4, \Delta_I \neq 0$, the following condition is satisfied

$$|\{x \in \mathbb{F}_2^4 \mid S(\Delta_I + x) + S(x) = \Delta_O\}| \leq 4$$

- For any fixed input difference $\Delta_I \in \mathbb{F}_2^4, \Delta_I \neq 0$ and output difference $\Delta_O \in \mathbb{F}_2^4$ such that $wt(\Delta_O) = wt(\Delta_I) = 1$, the following condition is satisfied

$$\{x \in \mathbb{F}_2^4 \mid S(\Delta_I + x) + S(x) = \Delta_O\} = \Phi$$

where $wt(x)$ is the hamming weight of x.

Substitution Layer

- For all $a \in \mathbb{F}_2^4, a \neq 0$ and $b \in \mathbb{F}_4$, $|S_b^W(a)| \leq 8$ holds.
- For all $a \in \mathbb{F}_2^4, a \neq 0$ and $b \in \mathbb{F}_4$ such that $wt(b) = wt(a) = 1$, $S_b^W(a) = \pm 4$ holds.

Cipher Design Contd.

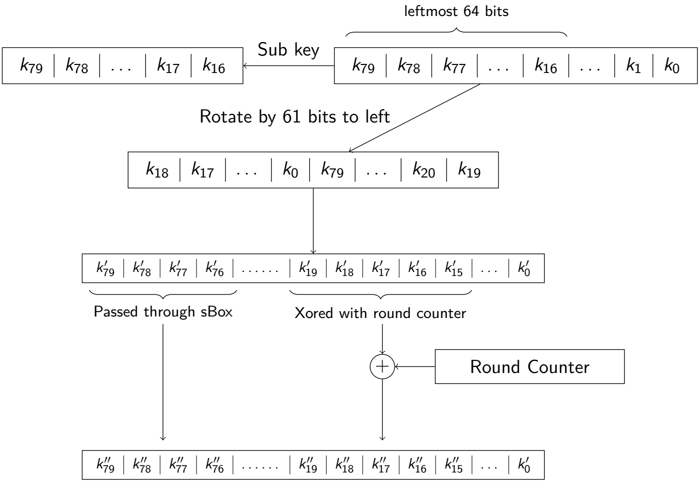
Permutation Layer

- Bit permutation.
- Bit i of STATE is moved to bit position $P(i)$.

$$P(i) = \begin{cases} 16.i \quad mod \quad 63 & i \in \{0, 1, \ldots 62\} \\ 63 & i = 63 \end{cases}$$

Key schedule Algorithm

We discuss the 80-bit key schedule algorithm.



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Round Reduced Attack

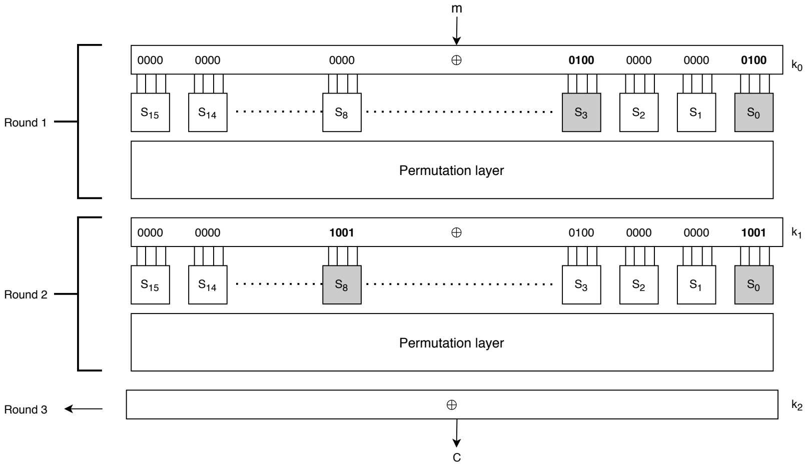

Figure: Attack Model

The Difference Distribution Table

Figure: DDT of the S-box

	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0	16	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0
1	0	0	0	4	0	0	0	4	0	4	0	0	0	4	0	0
2	0	0	0	2	0	4	2	0	0	0	2	0	2	2	2	0
3	0	2	0	2	2	0	4	2	0	0	2	2	0	0	0	0
4	0	0	0	0	0	4	2	2	0	2	2	0	2	0	2	0
5	0	2	0	0	2	0	0	0	0	2	2	2	4	2	0	0
6	0	0	2	0	0	0	2	0	2	0	0	4	2	0	0	4
7	0	4	2	0	0	0	2	0	2	0	0	0	2	0	0	4
8	0	0	0	2	0	0	0	2	0	2	0	4	0	2	0	4
9	0	0	2	0	4	0	2	0	2	0	0	0	2	0	4	0
A	0	0	2	2	0	4	0	0	2	0	2	0	0	2	2	0
B	0	2	0	0	2	0	0	0	4	2	2	2	0	2	0	0
C	0	0	2	0	0	4	0	2	2	2	2	0	0	0	2	0
D	0	2	4	2	2	0	0	2	0	0	2	2	0	0	0	0
E	0	0	2	2	0	0	2	2	2	2	0	0	2	2	0	0
F	0	4	0	0	4	0	0	0	0	0	0	0	0	0	4	4

Differential Characteristics

Table: Characteristics

Rounds		Diff.	Prob.
I		$x_0 = 4,\ x_4 = 4$	
R_1	k_0	$x_0 = 4,\ x_4 = 4$	1
R_1	S	$x_0 = 5,\ x_3 = 5$	2^{-4}
R_1	P	$x_0 = 9,\ x_8 = 9$	1
R_2	k_1	$x_0 = 9,\ x_8 = 9$	1

Characteristic

$$(x_0 = 4,\ x_3 = 4) \xrightarrow{\text{R}} (x_0 = 9,\ x_8 = 9)$$

Idea of filtering

- Decrease Wrong pair $\rightarrow$ Idea of filtering
- Observe from the DDT that transitions from $9 \rightarrow \{2, 4, 6, 8, c, e\}$
- Thus, after the effect of permutation layer of the second round, $c_1 \oplus c_2$ must belong to the set given below : $\{\{x_4 = 1, x_6 = 1\}, \{x_6 = 1, x_8 = 1\}, \{x_4 = 1, x_6 = 1, x_8 = 1\}, \{x_6 = 1, x_{12} = 1\}, \{x_6 = 1, x_8 = 1, x_{12} = 1\}, ...\}$ We have written code for this.

Filtering

Thus, message pair leading to the cipher text difference other than the above set, can be discarded. So, after filtering only 2^{14} plaintext pairs are left in our case.

Key Guess

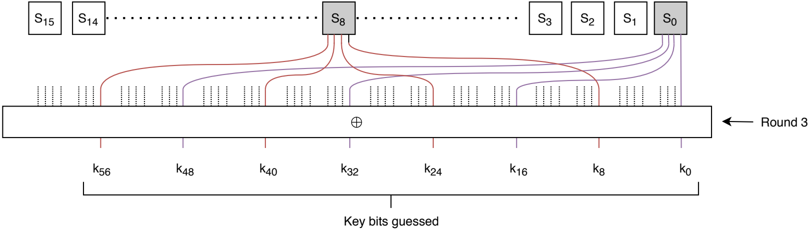

Figure: Guess 8 bits of the key k_2

We are able to find 8 bits of key k_2. In our case only 8 bit right subkey holds for all 2^{14} filtered pairs or in other word highest counter indicate the right 8 bit subkey.

Complexity Analysis

Complexity

(Data, Time, Memory) $= (2^{19}, 2^{25.17}, 2^{14})$

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LAT of the S-box

	0	1	2	3	4	5	6	7	8	9	A	B	C	D	E	F
0	8	-	-	-	-	-	-	-	-	-	-	-	-	-	-	-
1	-	-	-	-	-	-4	-	-4	-	-	-	-	-	-4	-	4
2	-	-	2	2	-2	-2	-	-	2	-2	-	4	-	4	-2	2
3	-	-	2	2	2	-2	-4	-	-2	2	-4	-	-	-	-2	-2
4	-	-	-2	2	-2	-2	-	4	-2	-2	-	-4	-	-	-2	2
5	-	-	-2	2	-2	2	-	-	2	2	-4	-	4	-	2	2
6	-	-	-	-4	-	-	-4	-	-	-4	-	-	4	-	-	-
7	-	-	-	4	4	-	-	-	-	-4	-	-	-	-	4	-
8	-	-	2	-2	-	-	-2	2	-2	2	-	-	-2	2	4	4
9	-	4	-2	-2	-	-	2	-2	-2	-2	-4	-	-2	2	-	-
A	-	-	4	-	2	2	2	-2	-	-	-	-4	2	2	-2	2
B	-	-4	-	-	-2	-2	2	-2	-4	-	-	-	2	2	2	-2
C	-	-	-	-	-2	-2	-2	-2	4	-	-	-4	-2	2	2	-2
D	-	4	4	-	-2	-2	2	2	-	-	-	-	2	-2	2	-2
E	-	-	2	2	-4	4	-2	-2	-2	-2	-	-	-2	-2	-	-
F	-	4	-2	2	-	-	-2	-2	-2	2	4	-	2	2	-	-

Table: Linear Approximation Table

Observations

- Maximum bias $\leq 2^{-2}$
- For a Single bit $\leq 2^{-3}$
- Bias Computation

$$2^{m-1} \prod_{i=1}^{m} \epsilon_i$$

Analysis

- Total 3 Cases to analyse the linear approximation of 4 rounds
- Results to bound the linear approximation bias for 28 rounds
- Let ϵ_{4R} be the maximal bias of a linear approximation of four rounds of present, then $\epsilon_{4R} \leq \frac{1}{2^7}$

Proof. . .

- Bias Calculation for 4 S-boxes:

$$\epsilon_4^4 \leq 2^{4-1} \times (2^{-2})^2 \times (2^{-3})^2 \implies \epsilon_4^4 \leq 2^{-7}$$

- Bias Calculation for 5 S-boxes:

$$\epsilon_4^5 \leq 2^{5-1} \times (2^{-2})^4 \times (2^{-3}) \implies \epsilon_4^5 \leq 2^{-7}$$

Resistant to the Linear Attack

- Maximal Bias for 28-round linear approximation
- Now assume that the cryptanalyst needs to approximate only only 28 rounds
- So total 2^{86} known plaintexts are required
- Which are greater than the available plaintexts space, that is 2^{64}
- Proved

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5-round integral distinguishers for PRESENT

Input:
(ccccccccccccccccccccccccccccccccccccccccccccccccccccccccccccaaaa)
Output:
(??bbbb)
c: constant bit, a: active bit, b: balanced bit, ?: unknown bit

Note

In this experiment, we are taking 2^{12} messages and varying right most 4 bits.

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Brownie Point

1. Using the idea of differential and filtering taught in the course, we have implemented a differential attack on 3 Rounds of PRESENT.
2. We have verified 5 Rounds integral property of PRESENT.

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Conclusion

- Understanding the design choices of PRESENT cipher.
- Properties of S-box
- Resistance against cryptographic attacks
- Implementation of 3-Rounds differential attack
- verify 5 round integral property
- Linear Cryptanalysis

Thanks

Team Members

- Ajay Tarole
- Ashish Kumar Suraj
- Rudraksh Kashyap

Implementation Info

- Github Link: https://github.com/ajay0090/PRESENT-Cipher