Narrow-Bicliques: Cryptanalysis of Full IDEA

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Cryptanalysis 101

- Differential attacks
- Linear attacks

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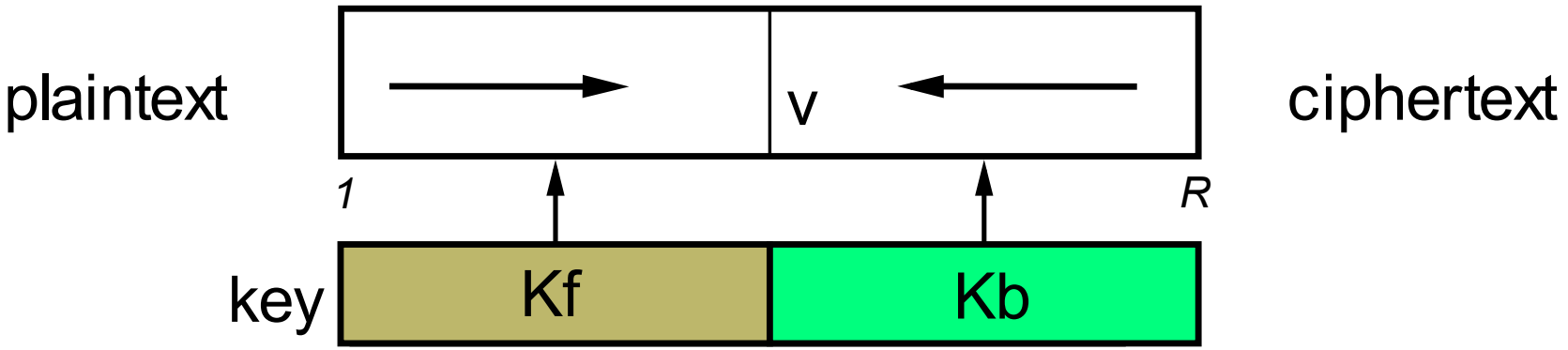
- Linear attacks

- Why? Powerful, versatile, found many applications since early 90s
- Many variants
- Impact on cipher design: proofs against classes of those attacks are state-of-the-art

Meet-in-the-middle attacks



- Overshadowed by differential and linear attacks in recent 20+ years
- Changing since attack on lightweight cipher KTANTAN (SAC 2010 and later)

Outline

- Setting
- Review of meet-in-the-middle attacks
- Description of IDEA
- Attacks on
  - 6 rounds (shortcut)
  - 7.5 rounds (shortcut)
  - Full 8.5 rounds (bruteforce-like)
- Conclusion and future work

The setting

- Given: A block cipher
- Goal: find the single unknown key
- Cryptanalyst is allowed to choose plaintexts and ask for their ciphertexts (CPA)

Brute-force:

guess all 2^k keys for success probability 1

MITM attacks on Symmetric Primitives

Block ciphers

Diffie-Hellman 77

MITM on 2-key 2-DES

Merkle-Hellman 81

MITM on 2-key 3-DES

Chaum-Evertse 85

6-7 rounds of DES

Hash functions

MITM attacks on Symmetric Primitives

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Lai-Massey 92

2nd-preimage on iterated constructions

Aoki-Sasaki et al. 08-10

Preimage for MD5, ...

Guo-R. et al. 10

Preimages for Tiger, ...

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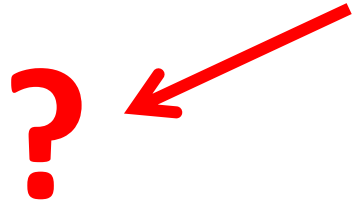

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KTANTAN Key-recovery

Wei-R. et al. 11

Improved KTANTAN Key-recovery

Hash functions

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Improvements with „Biclique“ view: SHA-2, Skein

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New AES Results	*Improvements with „Biclique“ view: SHA-2, Skein*

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New IDEA Results	

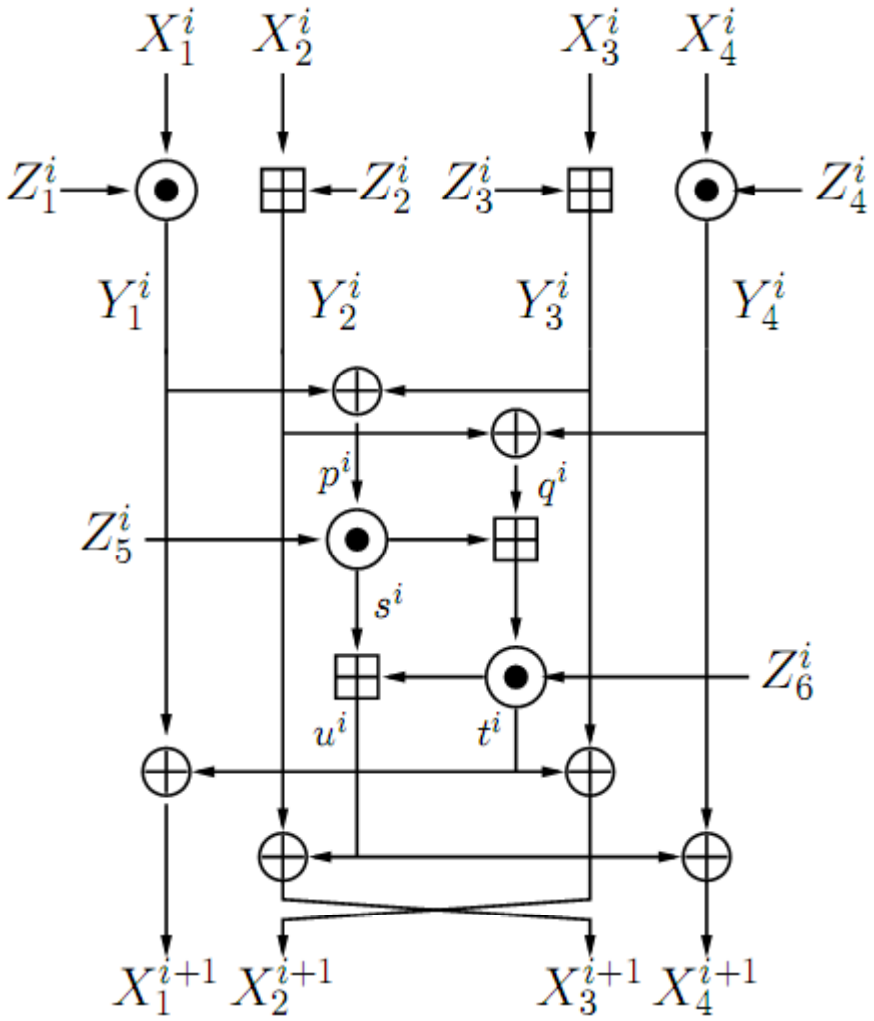
The Biclique approach

- Formalization of „Initial structure“ concept due to Aoki-Sasaki 09
- Mapping to differential framework possible and intuitive
  - Differential characteristics/trails
  - Neutral bits
  - Rebound techniques
- Analyzing more rounds possible

IDEA

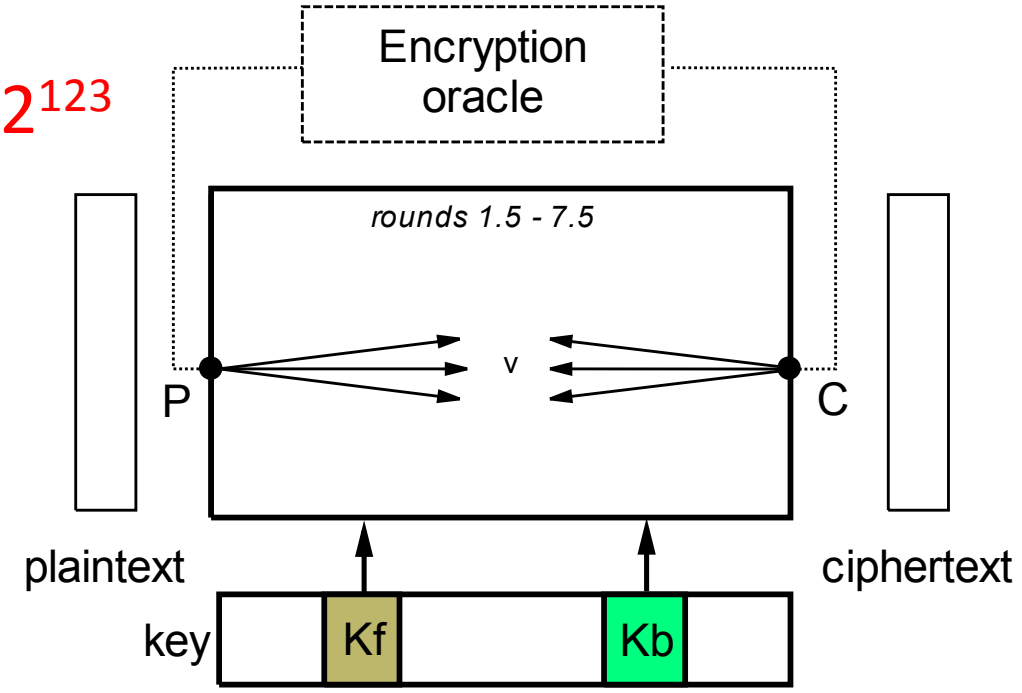
- Designed by Lai and Massey, 91
- 64-bit blocks, 128-bit key
- Widely implemented
- 20+ research papers
- So far: best published result on 5/6 out of 8.5 rounds by Sun-Lai 09:
  - first 5-round: 2^{17} data and $2^{125.5}$ time or
    2^{64} data and 2^{115} time
  - middle 6-round: better results

IDEA Round


X_1^i X_2^i X_3^i X_4^i
Z_1^i Z_2^i Z_3^i Z_4^i
Y_1^i Y_2^i Y_3^i Y_4^i
p^i q^i
Z_5^i
s^i
Z_6^i
u^i t^i
X_1^{i+1} X_2^{i+1} X_3^{i+1} X_4^{i+1}

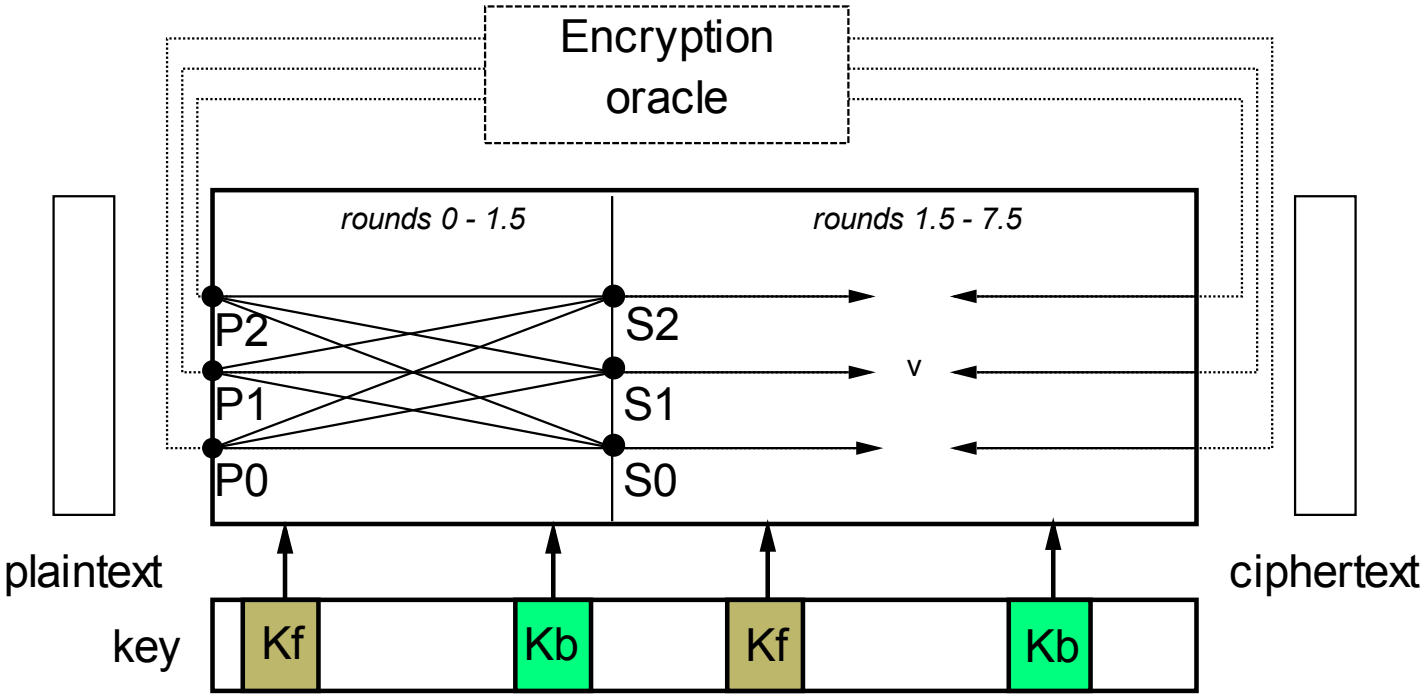
MITM on IDEA

- Crypto 2011 Rump Session, Biham et al.: MITM attacks on up to 6 (middle) rounds
- Example: variant with 2 plaintext/ciphertext pairs
  - Time: about 2^{123}



Bicliques and IDEA

- Initial biclique result: attack on 7.5 rounds
- Problem: Half of codebook needed
- Time: again about 2^{123}



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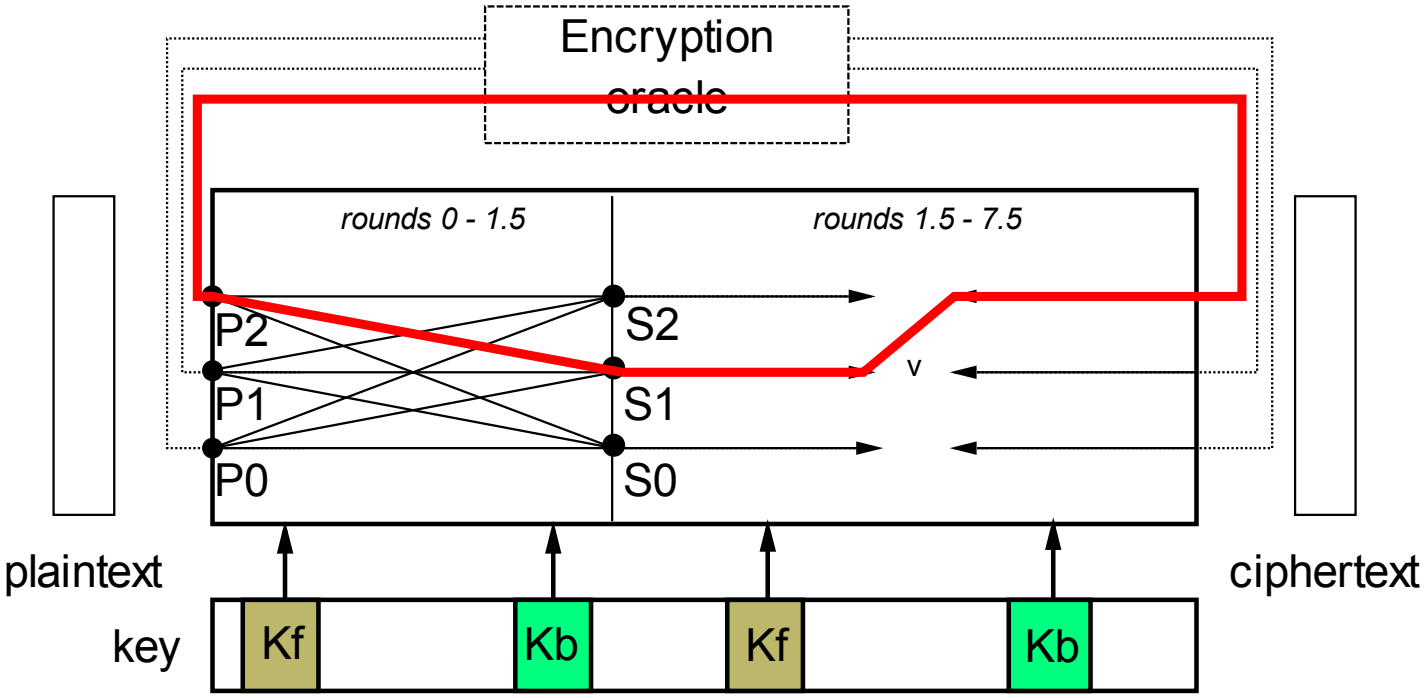

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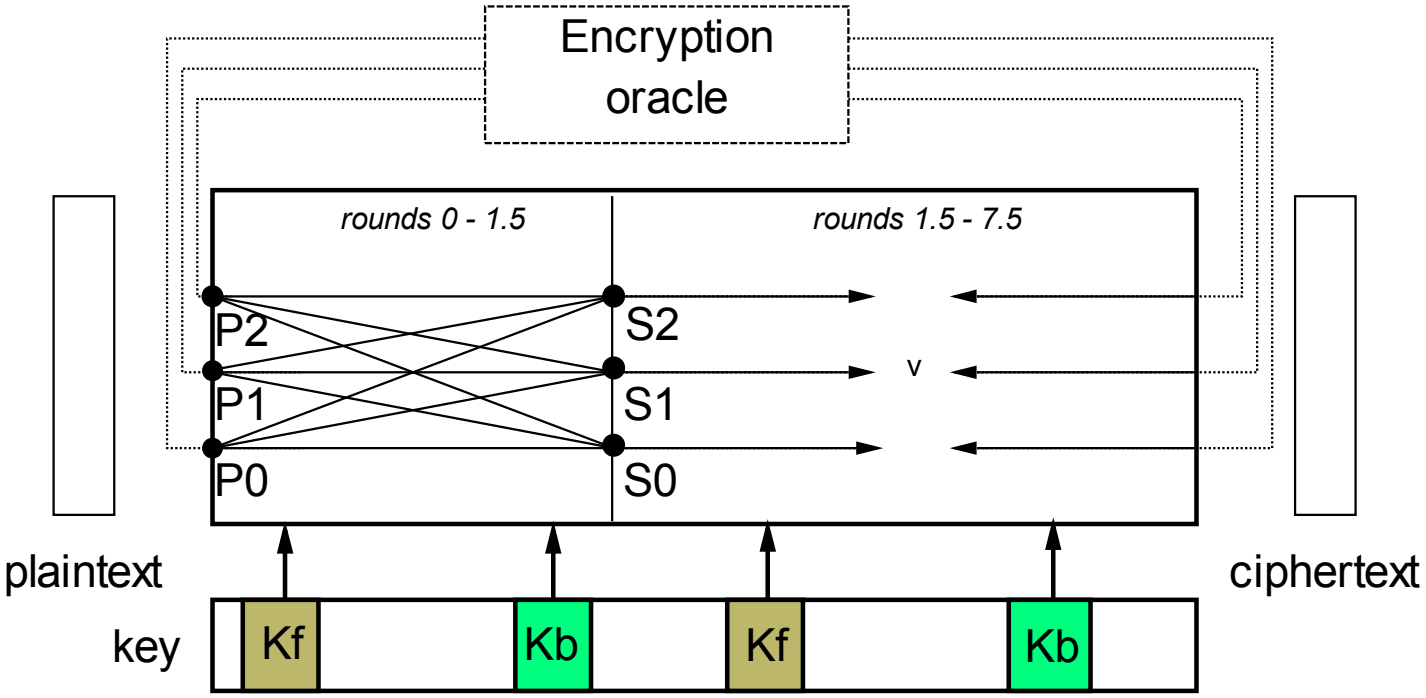

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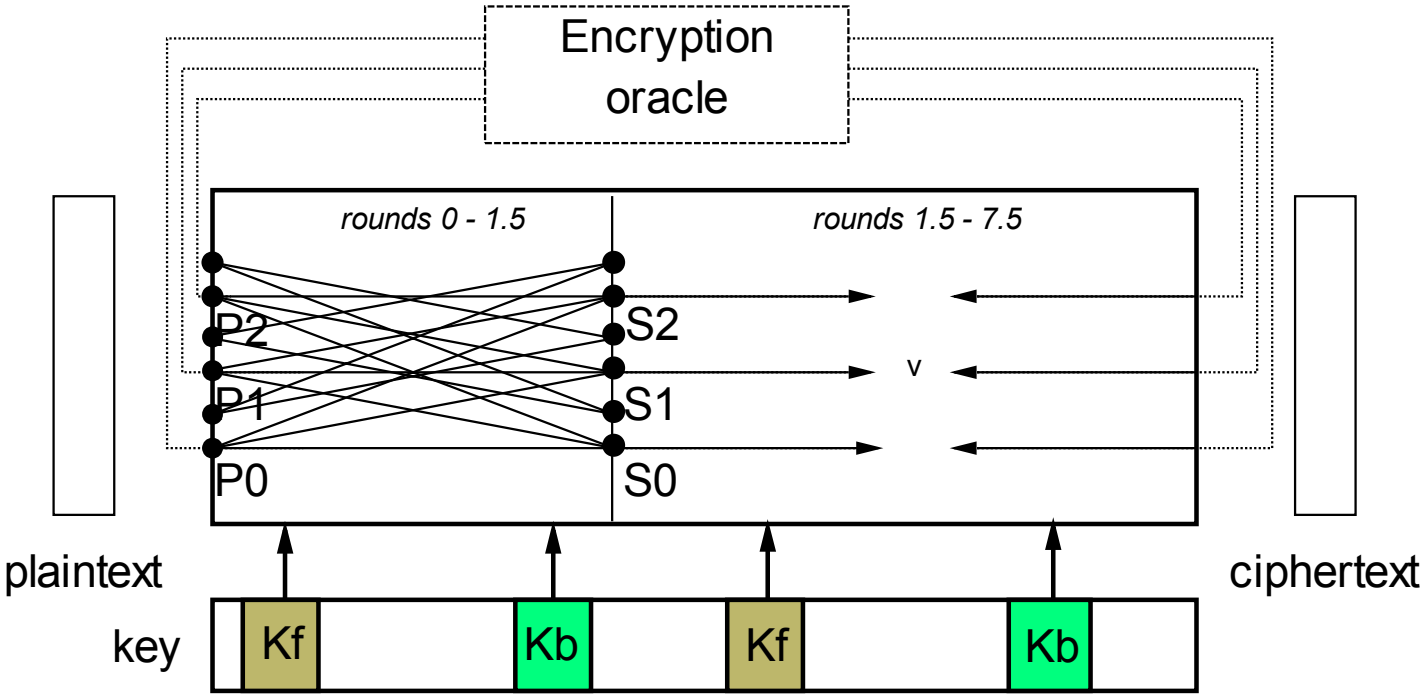

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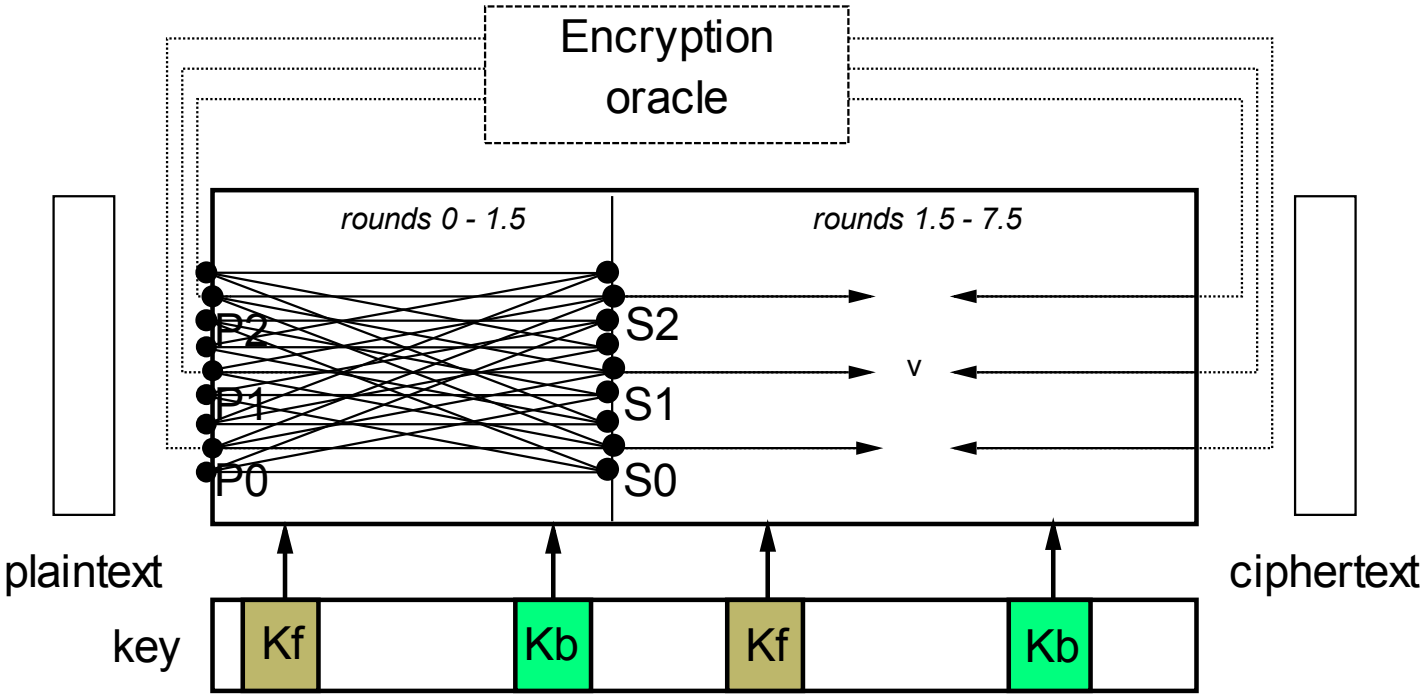


Narrow Bicliques and IDEA

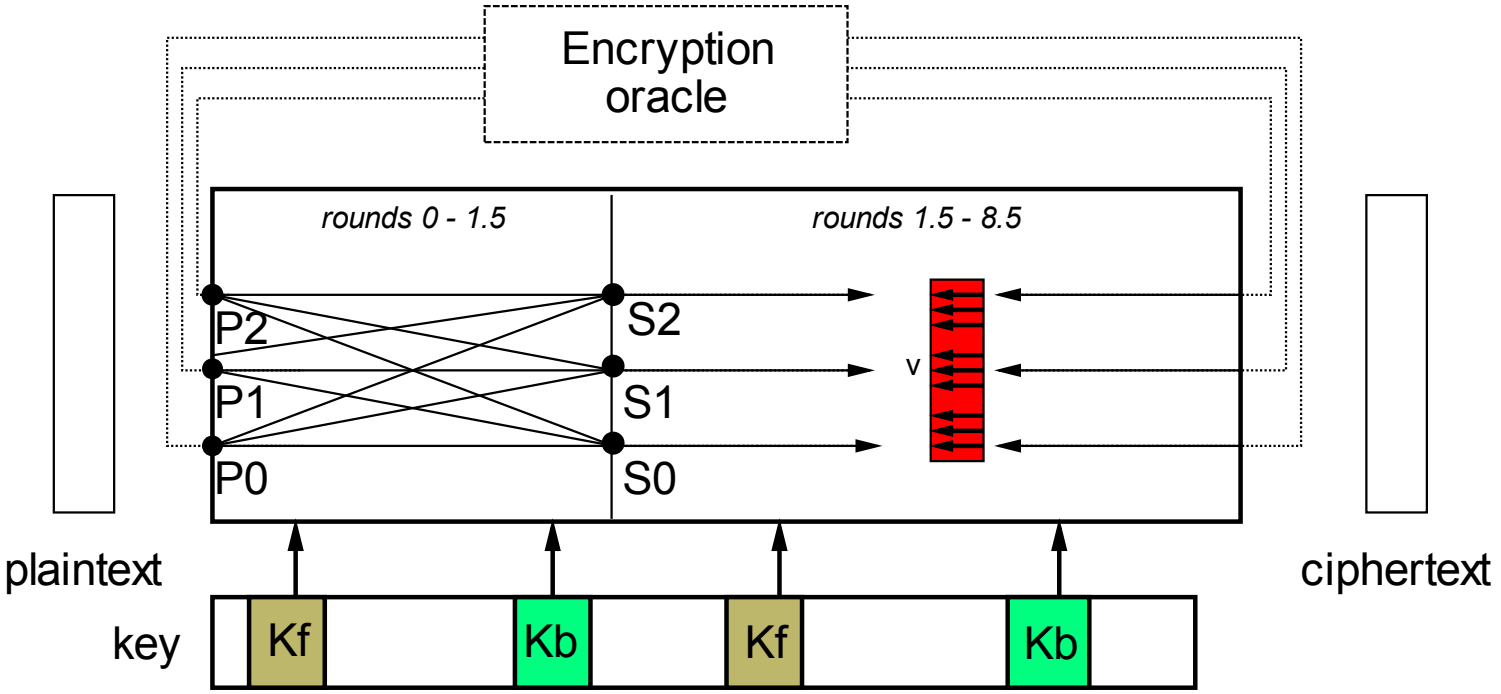
- Address the problem of exploding data requirements
- New tricks:
  - Efficiently, for every key group, find internal state variables such that resulting plaintexts collide in as many bits as possible
  - Multiple bicliques per key group
- Can be complicated: practically verified

Examples of results (those minimizing time complexity)

Rounds	Data complexity Biclique	Data complexity Narrow Biclique	time
first 5	63	25	101,5
first 6	63	41	118,9
first 7.5	63	52	123,9

Narrow Bicliques and full IDEA

- Next biclique application: attack on full 8.5 rounds. 1-round brute-force in matching part.
- Time: about 2^{126}



More examples of results

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full (8.5)	63	59	125,97
full (8.5)	63	52	126,06

Conclusions

- Two main contributions:
  - Much improved cryptanalysis (reduced) IDEA
    - See also recent update of Biham et al. eprint 2011/417
  - New tool for the biclique framework

- Biclique attacks million times faster than brute-force for reduced-round variants

- Broken? If AES is „broken“, then so is IDEA (also about **126 bit security**)

Open Problems

- More ideas from hash cryptanalysis applicable to cipher cryptanalysis?
- New variants of and targets for biclique cryptanalysis
- Explore new sub-discipline:

  bruteforce-like cryptanalysis

  Interesting case: Improve optimized brute-force attacks on ciphers with 80-bit keys (or less)

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Q&A

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