Chaskey: a Lightweight MAC Algorithm for Microcontrollers

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MAC Algorithm for Microcontrollers

Message Authentication Code (MAC)

- $\mathsf{MAC}_K(m) = \tau$
- Authenticity, no confidentiality
- Same key for MAC generation and verification

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Microcontroller

- Cheap 8/16/32-bit processor: USD 25-50¢
- Applications: home, medical, industrial,...
- Ubiquitous: 30-100 in any recent car

Design

Requirements

- Drop-in replacement for AES-CMAC
  (variant of CBC-MAC for variable-length messages)
- Same functionality and security

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Approach

- Dedicated design for microcontrollers

Commonly used MACs

Based on (cryptographic) hash function

- **Example:** HMAC, SHA3-MAC
- Large block size, collision resistance unnecessary

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Based on block cipher

- **Example:** CMAC

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Based on block cipher

- **Example:** CMAC
- **Problem:** ten times too slow!

Our Approach

Every cycle counts!

- Avoid load/store: keep data in registers
- Avoid bit masking
- Make optimal use of instruction set

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Bridging the gap

- Provable security
- Cryptanalysis
- Implementation

Primitive

Which primitive?

- Cryptographic hash function ✗

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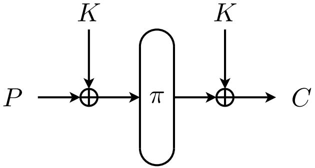
$\left.\begin{array}{l}\text{Block cipher ✗}\\ \text{Ideal permutation ✗}\end{array}\right\} \rightarrow$ Even-Mansour Block Cipher ✓



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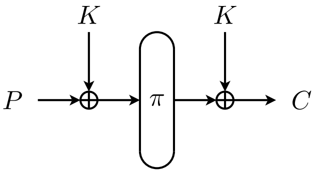
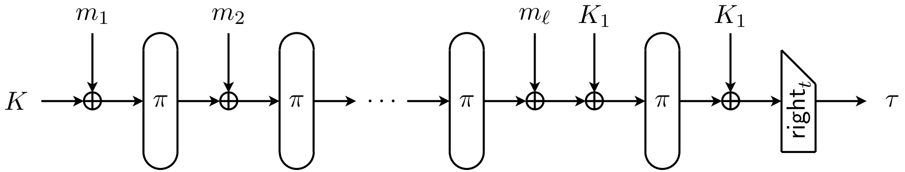


Related-key attacks

- Insecure, so choose uniformly random keys!

Chaskey: Mode of Operation

- Split m into ℓ blocks of n bits
- Top: $|m_\ell| = n$
- $K_1 = 2K$



Chaskey: Mode of Operation

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- Top: $|m_\ell| = n$, bottom: $0 \leq |m_\ell| < n$
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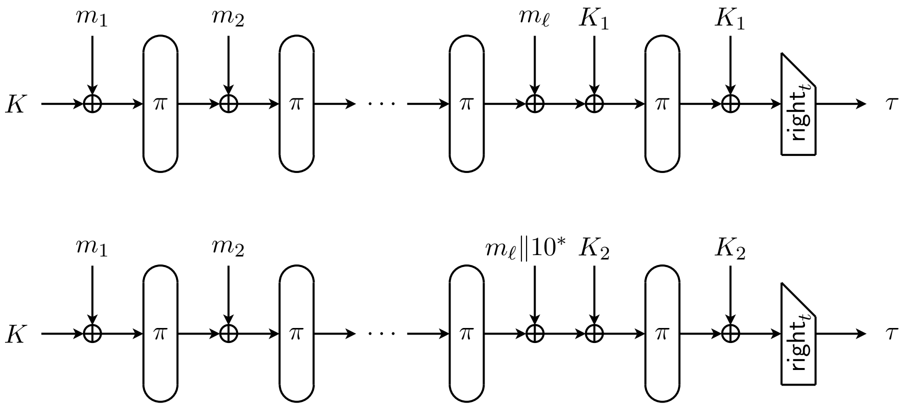

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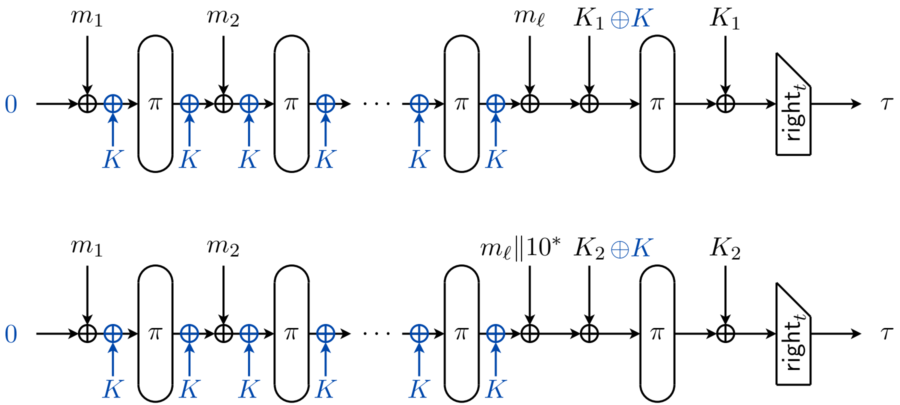

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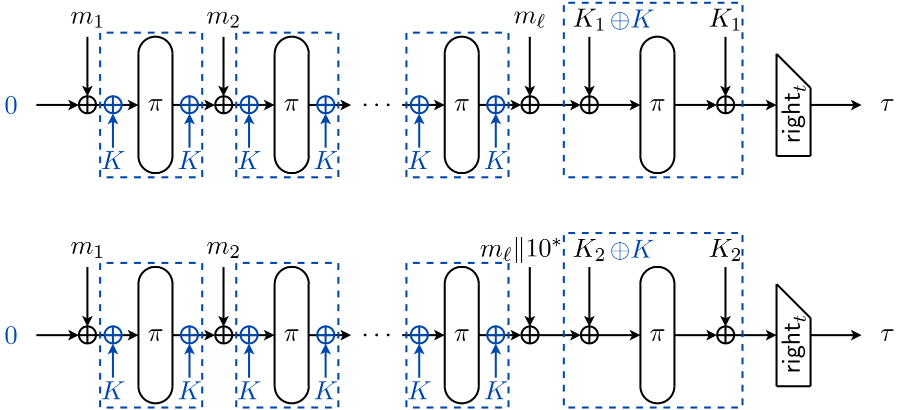

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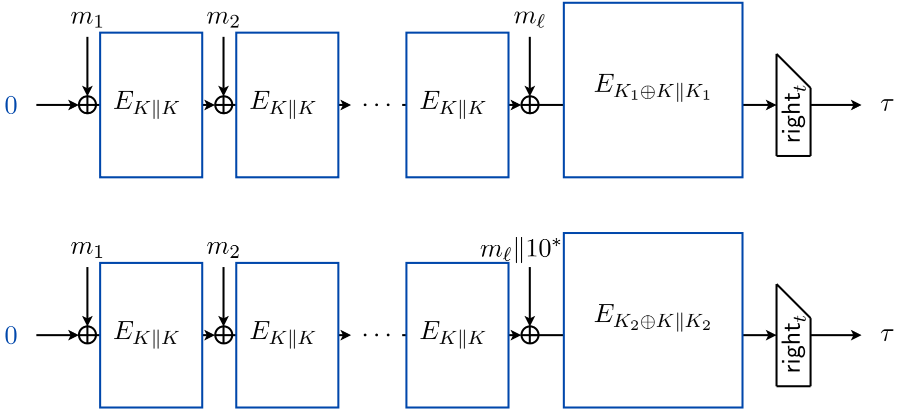

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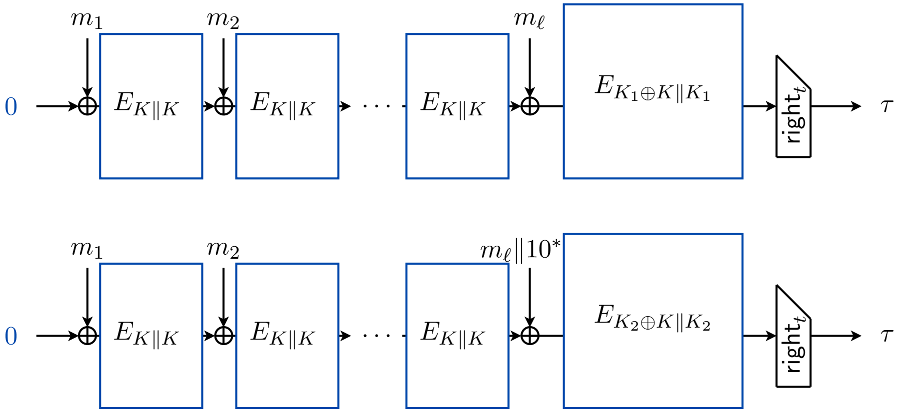
variant of FCBC [BR'00]



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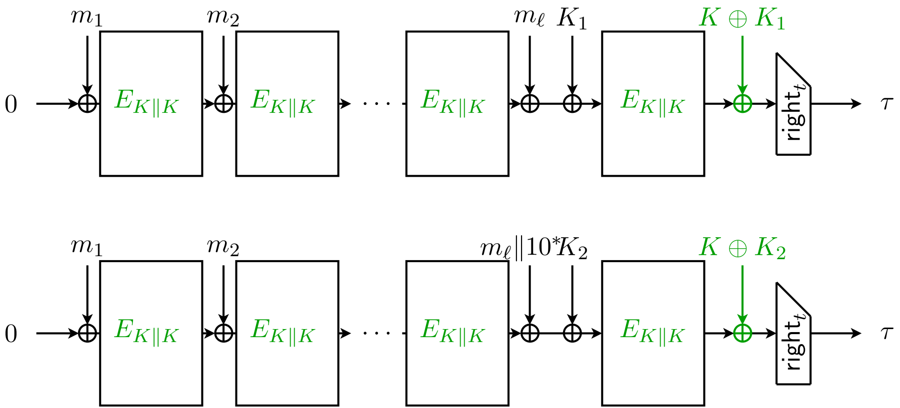

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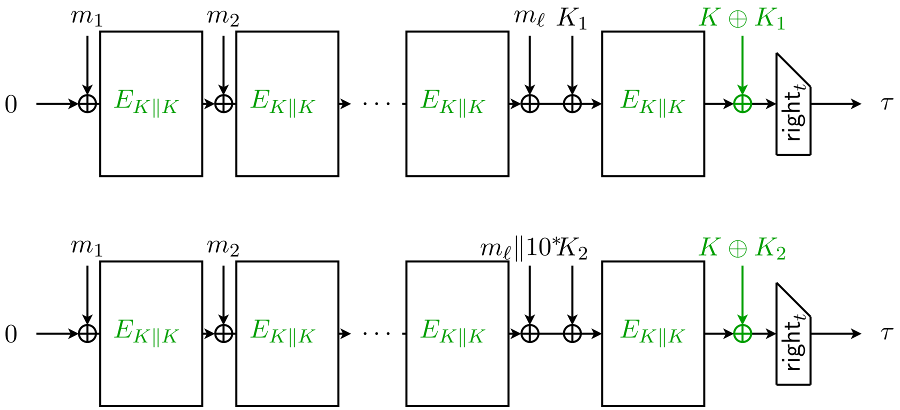

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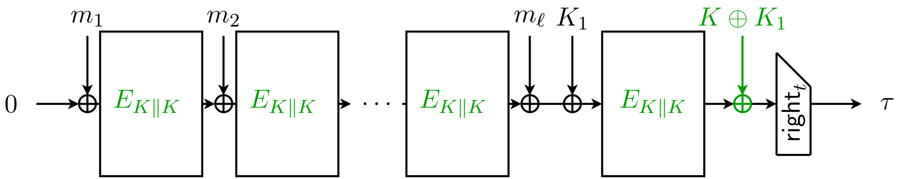
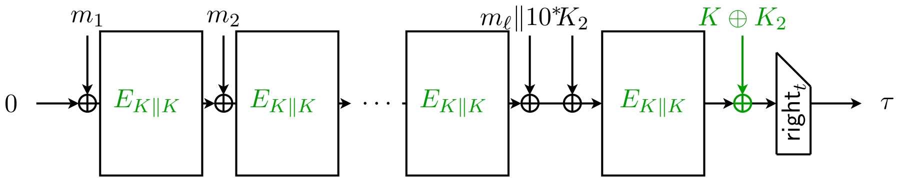


2 Even-Mansour



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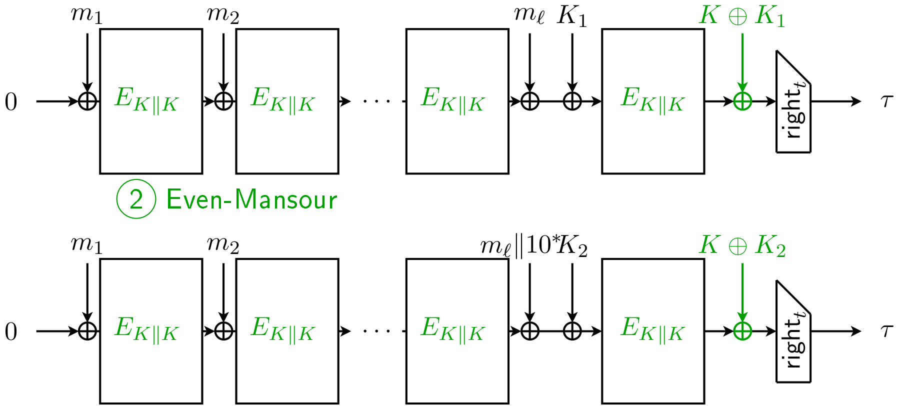
3 not in CMAC



Cryptanalysis

MAC forgery: find new valid (m, τ)

- D: data complexity (# blocks of chosen messages)
- T: time complexity (# permutation evaluations)

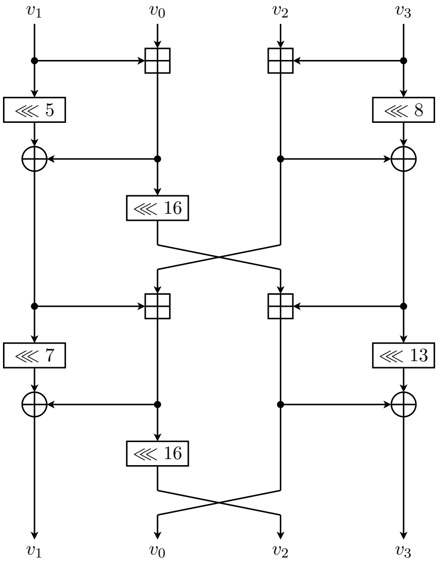
Attacks

- Internal collision: $D \approx 2^{n/2}$
- Key recovery: $T \approx 2^n / D$
- Tag guessing: $\approx 2^t$ guesses

Chaskey parameters

- Key size, block size: $n = 128$, tag length: $t \geq 64$

Permutation



Design

- Add-Rot-XOR (ARX)
- Inspired by SipHash
- 32-bit words
- 8 rounds

Properties

- Rotations by 8, 16:
  faster on 8-bit μC
- Fixed point: $0 \to 0$
- Cryptanalysis: rotational, (truncated) differential, MitM, slide,... see paper!

Chaskey: Speed Optimized (gcc -O2)

Microcontroller	Algorithm	Data [byte]	ROM [byte]	Speed [cycles/byte]
Cortex-M0	AES-128-CMAC	16	13 492	173.4
		128	13 492	136.5
	Chaskey	16	1 308	21.3
		128	1 308	18.3
Cortex-M4	AES-128-CMAC	16	28 524	118.3
		128	28 524	105.0
	Chaskey	16	908	10.6
		128	908	7.0

Chaskey: Even Faster! Thanks to Björn Haase

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Summary

Chaskey:
MAC algorithm for 32-bit microcontrollers

- Addition-Rotation-XOR (ARX)
- Even-Mansour block cipher
- ARM Cortex-M: 7-15$\times$ faster than AES-128-CMAC

Summary

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More info, updates:

http://mouha.be/chaskey

Questions?

Supporting Slides

Chaskey: Size Optimized (gcc -Os)

Microcontroller	Algorithm	Data [byte]	ROM [byte]	Speed [cycles/byte]
Cortex-M0	AES-128-CMAC	16	11 664	176.4
		128	11 664	140.0
	Chaskey	16	414	21.8
		128	414	16.9
Cortex-M4	AES-128-CMAC	16	10 925	127.5
		128	10 925	89.4
	Chaskey	16	402	16.1
		128	402	11.2

Security Proof

MAC forgery: find new valid (m, τ)

- D: block cipher (PRP) queries
- T: permutation queries

Standard Model

- $\mathbf{Adv}^{\mathsf{mac}}_{\text{Chaskey-B}}(q, D, r) \leq \frac{2D^2}{2^n} + \frac{1}{2^t} + \mathbf{Adv}^{\mathsf{3prp}}_{E}(D, r)$

Ideal Permutation Model

- $\mathbf{Adv}^{\mathsf{mac}}_{\text{Chaskey}}(q, D, r) \leq \frac{2D^2}{2^n} + \frac{1}{2^t} + \frac{D^2 + 2DT}{2^n}$