Using Keccak technology for AE: Ketje, Keyak and more

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Outline

Secure channels [Patterson, Crypto summer school Croatia 2014]

Secure channels widely deployed:

- SSL/TLS, DTLS, IPsec, SSH, OpenVPN
- WEP, WPA, WPA2
- GSM, UMTS, LTE
- Cryptocat, OTR, SilentCircle
- ISO 7816-4, Global Platform SCP 01, 02, 03, 11, ...
- Bluetooth, DECT, ...
- ...

Desired security [Patterson, Crypto summer school Croatia 2014]

Message confidentiality, integrity and origin authentication

- Channel and endpoint characteristics
  - stream-based or message-oriented
  - single-direction, half-duplex, full-duplex
  - with(-out) handling of errors: lost packets, noise, ...
  - side-channel leakage, faults
  - release of unverified plaintext, ...
- Against different types of attackers
  - passive: see ciphertexts and (some) plaintexts
  - active: can modify, delete, inject and re-order messages
- Additional protection:
  - semantic and multi-message: replay, message dropping, re-ordering
  - time-related: freshness
  - surveillance-related: traffic analysis
  - denial-of-service

Authenticated encryption in a secure channel

- AE is just a building block, security also relies on:
  - key establishment, key management, user interface, ...
- Good engineering: build in security from the getgo
  - leads to efficient and effective solutions
  - in most cases nonces are required to protect against replay
- Unfortunately not all is based on good engineering
  - successful products often proof-of-concepts gotten out of hand
  - security has to be bolted on afterwards
  - sometimes there is no more room for a nonce

KECCAK supports both nonce-based and nonceless AE!

What do we mean by KECCAK-based AE?

- Underlying primitive: KECCAK-$p[b, n_r]$ [FIPS 202 draft, 2014]
  - sharing of software/hardware with SHA-3
  - security assurance thanks to public scrutiny since 2008
  - efficient side-channel protection
- Range of parameters larger than in SHA-3 hashes and XOFs:
  - widths: $b \in \{200, 400, 800, 1600\}$
  - default number of rounds : $n_r = 12$
  - in MONKEYDUPLEX and DONKEYSPONGE: $n_r \in \{1, 2, 6, 12\}$
- Target security strength: 128 bits
  - including multi-target attacks

KECCAK-based AE modes: two approaches

KEYAK:

- official duplex and sponge
- strong permutation
  - 12 rounds
  - block-oriented
  - *hermetic*
- cryptanalysis
  - permutation-level

KETJE et al.:

- MONKEYDUPLEX and DONKEYSPONGE
- (thin) round function
  - #rounds in phases
  - stream-oriented
  - relying on e.g. max DP
- cryptanalysis
  - construction + round function

Outline

Our CAESAR candidate KEYAK

- Nonce-based
- Sequence of header-body pairs
  - keeps state during the session
- Optionally parallelizable
- Using
  - KECCAK-$p[1600, n_r = 12]$
  - KECCAK-$p[800, n_r = 12]$

Keyak instances and efficiency

Name	Width b	Parallelism P
Ocean Keyak	1600	4
Sea Keyak	1600	2
Lake Keyak	1600	1
River Keyak	800	1

- Processing
  - long messages: about 50 % of SHAKE128
  - short messages: 24 rounds
- Working memory footprint
  - reasonable on high- and middle-end platforms
  - not ideal on constrained platforms

Outline

Our CAESAR candidate KETJE

- Nonce-based
- Sequence of header-body pairs
- Small footprint
- Reduce footprint while keeping high security strength:
  - use KECCAK-$p[200, n_r]$ (96-bit security) or KECCAK-$p[400, n_r]$
  - MONKEYDUPLEX instead of duplex
  - more ad-hoc security
  - strong reliance on nonce uniqueness
- Target niche: secure channel protocol on secure chips
  - banking card, ID, (U)SIM, secure element, FIDO, etc.
  - secure chip has strictly incrementing counter

KETJE instances

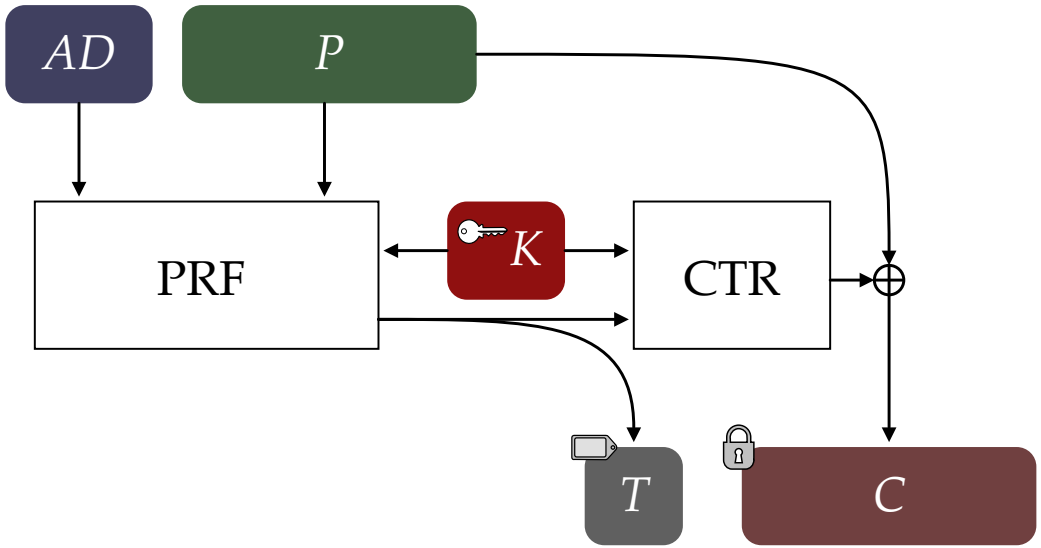
feature		KETJE JR	KETJE SR
state size		25 bytes	50 bytes
block size		2 bytes	4 bytes
processing		**computational cost**	
initialization	per session	12 rounds	12 rounds
wrapping	per block	1 round	1 round
8-byte tag comp.	per message	9 rounds	7 rounds

KEYAK and KETJE in absence of nonces

- KEYAK may leak plaintext information
  - XOR of 1st differing plaintext blocks in otherwise identical sessions
- KETJE may break down completely
  - single-round differential attacks become possible

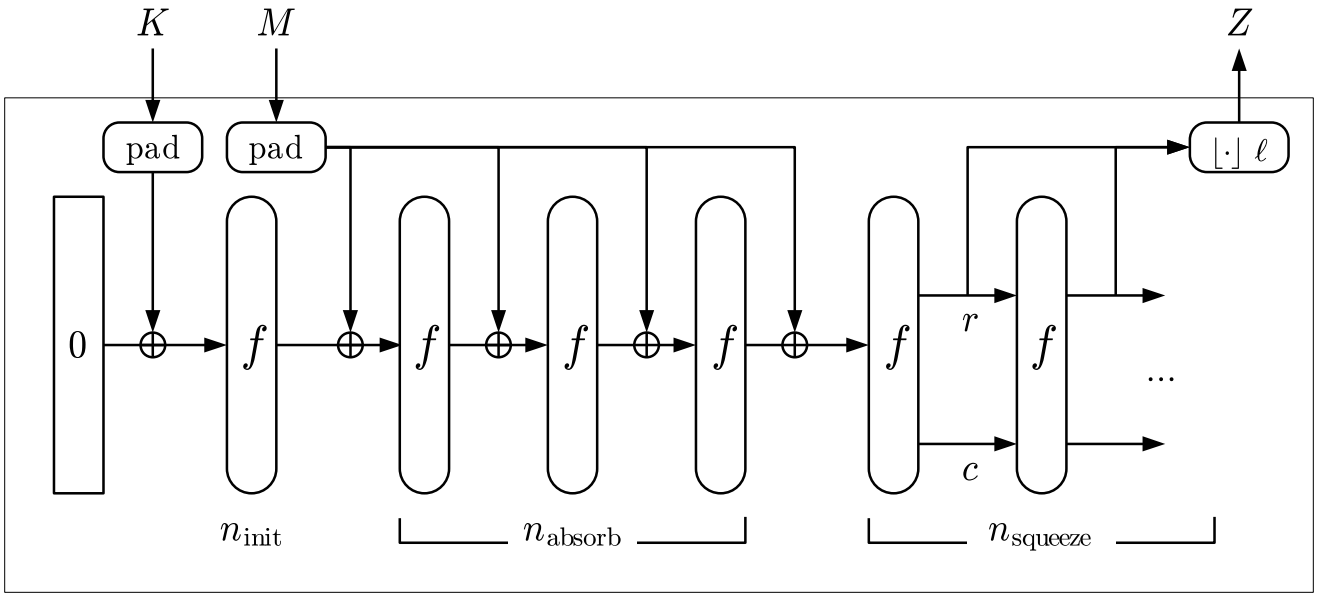
Outline

HAddoc: the concept



- Permutation-based variant of SIV [Rogaway, Shrimpton 2006]
- Nonceless
- Leakage limited to:
  - length of messages
  - identical messages (AD, P) give identical cryptograms (C, T)

Inside Haddoc: the donkeySponge PRF



donkey sponge

- Absorbing phase exploits state secrecy [DR, Pelican, 2005]:
  - usage of full state width b
  - $n_{\text{init}} = 2$: make all state bits depend on the key
  - $n_{\text{absorb}} = 6$: limit max DP to prevent state collisions
- Squeezing phase: $n_{\text{squeeze}} = 12, c = 256$

Building blocks of Haddoc

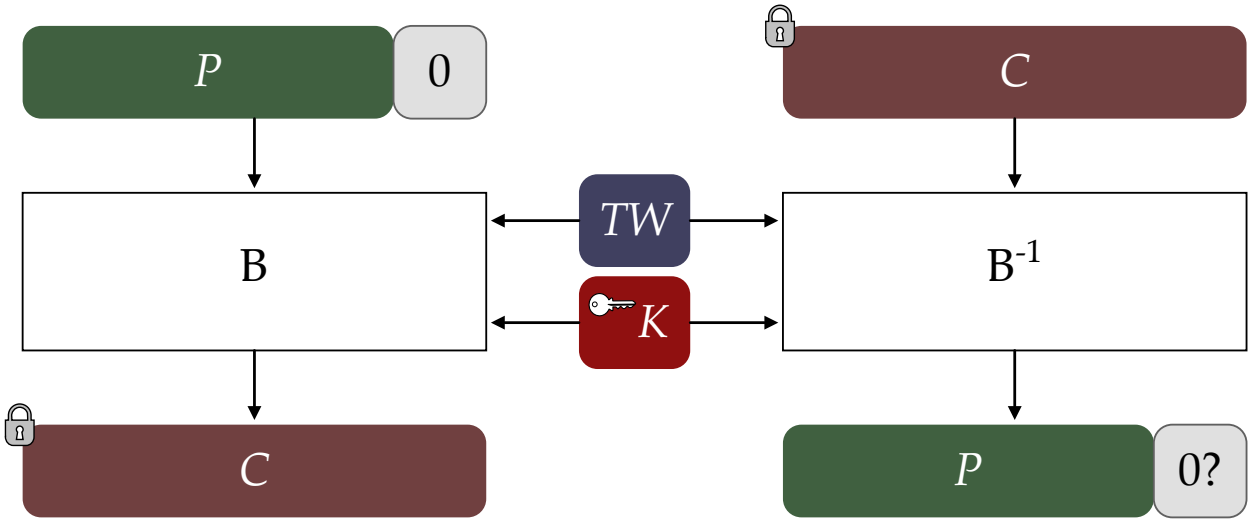
- PRF: donkeySponge with
  - input K: key
  - input M: injective coding of (AD, P)
  - output $T = \lfloor Z \rfloor_{256}$
- CTR: sponge in counter mode
  - single-block in- and outputs
  - $Z_i = \text{sponge}(K||T||i)$
  - $C_i = M_i \oplus Z_i$
  - $n_r = 12$
- Permutations
  - Keccak-$p[1600, n_r]$
  - Keccak-$p[800, n_r]$

HAddoc features

- Processing:
  - long messages: about 70 % of SHAKE128
  - short messages: 26 rounds
  - if P is absent we get a MAC function:
    - long messages: about 21 % of SHAKE128
    - short messages: 14 rounds
- Advantages
  - decryption: random access
  - encryption: PRF parallelizable
- Disadvantages
  - encryption strictly two-pass
  - message expansion by $2n$-bit tag for n-bit security

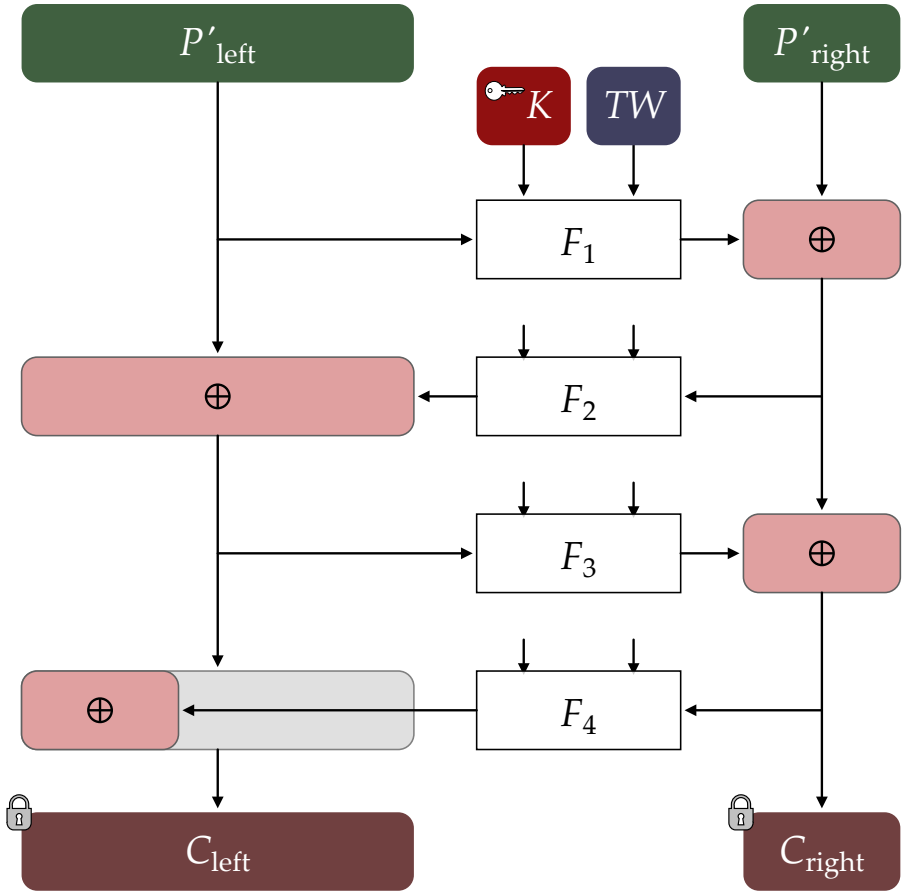
Outline

Mr. Monster Burrito: the concept



- Robust AE [Rogaway, ACNS 2014]
  - inspired by AEZ [Hoang, Krovetz, Rogaway, Shrimpton 2014]
  - wide tweakable block cipher
  - variable key-, tweak- and blocksize: $|K|$, $|TW|$ and $|B|$
- *Best possible forgery resistance for given message expansion*

Inside Mr. Monster Burrito



- Based on [Naor Reingold 1997], thanks [DJB, Tenerife 2013]
  - F_2 and F_3: PRF
  - F_1 and F_4: constraint is max DP $< 2^{-256}$

Building blocks of Mr. Monster Burrito

- Asymmetric Feistel: right part is single block
- F_i: donkeySponge instances as in Haddoc PRF
- F_i input:
  - K: key
  - M: injective coding of $(|B|, TW, S_{\text{left/right}}, i)$
- F_i output length:
  - F_1, F_3 and F_4: single-block
  - F_2: same length as left part
- Permutations
  - Keccak-$p[1600, n_r]$
  - Keccak-$p[800, n_r]$

Mr. Monster Burrito features

- Processing
  - block length above rate: close to 100% of SHAKE128
  - short block length: 56 rounds
- Advantages
  - minimum data expansion for given anti-forgery level
  - can even exploit redundancy in plaintext
- Disadvantages: *heavyweight crypto*
  - four-pass
  - inefficient for small block lengths

Conclusions

Keccak-based AE:

- our preferred: CAESAR-candidate Keyak
- constrained platforms: CAESAR-candidate Ketje
- nonceless: Haddoc and Mr. Monster Burrito
  - will not win beauty contest
  - but performance degradation is not dramatic

Inspired by [Rogaway on AE, ACNS 2014]

Thanks for your attention!