SILC: SImple Lightweight CFB

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DIAC 2014
August 23, 2014, Santa Barbara, USA

Outline

- Authenticated Encryption with Associated Data (AEAD)
- SILC, SImple Lightweight CFB, pronounced as "silk"

http://pixabay.com/en/silk-yarn-thread-spool-thread-196539/

SILC Design Goal

- Provably secure AEAD that is based on a blockcipher
  - Standard security notions for privacy and authenticity
- To improve previous schemes, CCM, EAX, and EAX-prime
  - optimizing the design to achieve a small gate size on HW implementations
- HW oriented version of CLOC [IMGM14]
  - CLOC is for embedded SW implementations

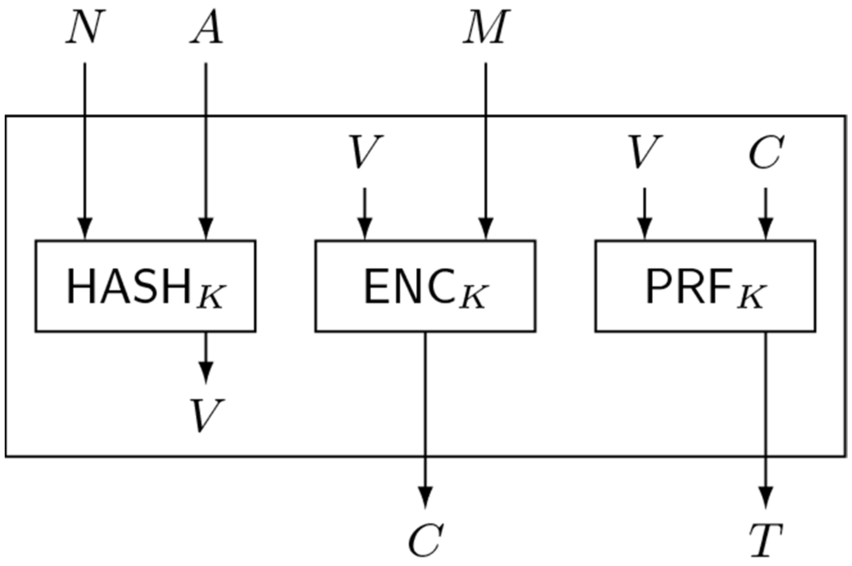
[IMGM14] Iwata, Minematsu, Guo, Morioka, CLOC: Compact Low-Overhead CFB, Submission to the CAESAR competition

Design Strategy

- CLOC optimizes the number of blockcipher calls by making various cases
  - if the input is empty, a multiple of block size, or otherwise
  - this contributes to the efficiency for short input, and well suits for embedded SW implementations
  - requires non-negligible number of logic gates
- SILC avoids making cases
  - at the cost of the constant number of increase of blockcipher calls
  - data blocks are processed consistently
  - reduces the logic gates needed to implement the cases

SILC Overview

- SILC is built upon CLOC
- It follows the Encrypt-then-PRF paradigm
- HASH, PRF: variants of CBC MAC
- ENC: a variant of CFB



Parameters

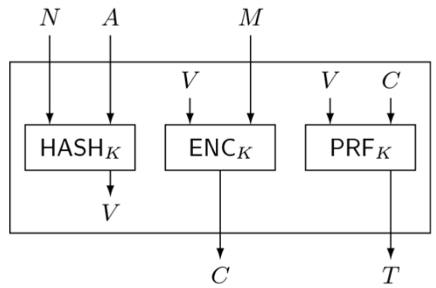
- E_K: blockcipher with an n-bit block
- l_N: nonce length in bits

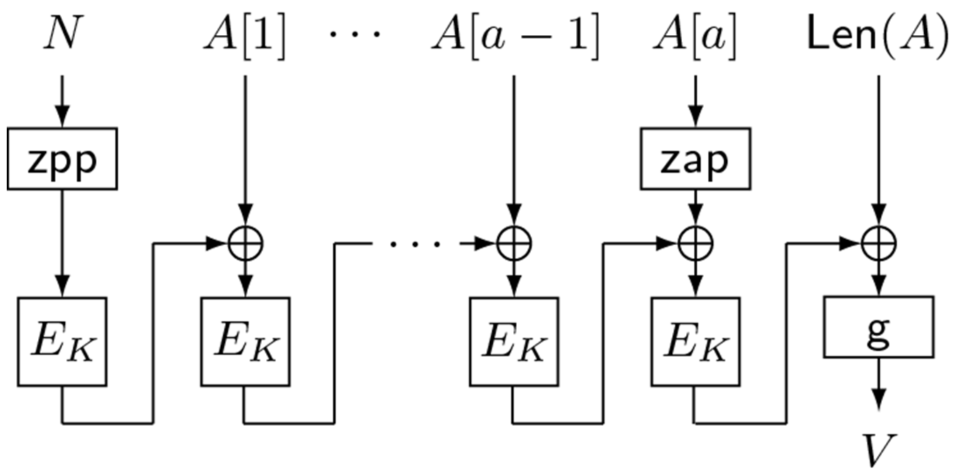
  $1 \leqq l_N \leqq n-1$
- tau: tag length in bits

  $1 \leqq tau \leqq n$

V <- $HASH_K(N,A)$

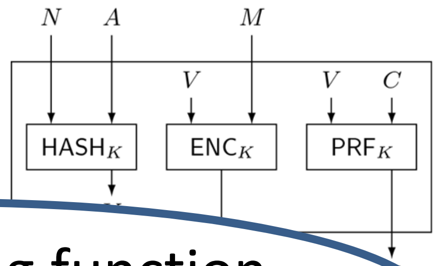
- variant of CBC MAC
- N: nonce, fixed length, $1 \leqq |N| \leqq n-1$
- A: associated data, at most $2^{n/2}$-1 bytes



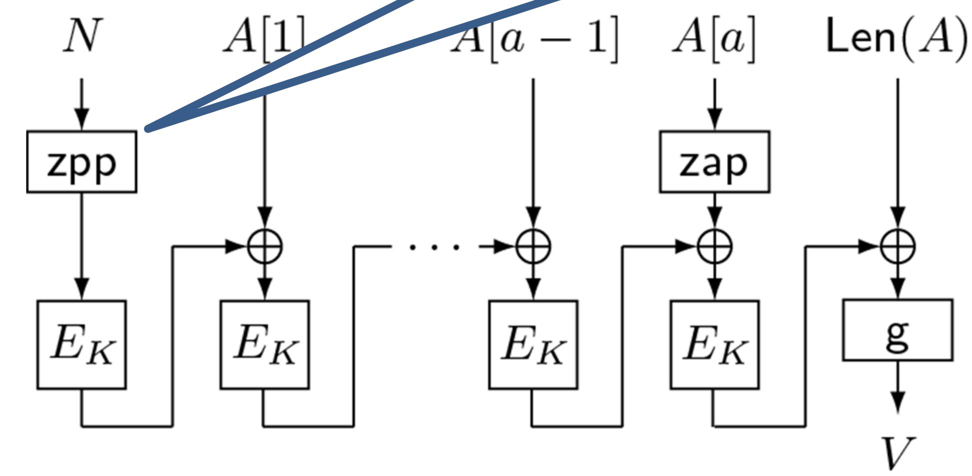


V <- $HASH_K$(N,A)

- variant of CBC MAC
- N: nonce, fixed length, 1 ≦ |N| ≦ n−1
- A: associated data, at most $2^{n/2}$-1



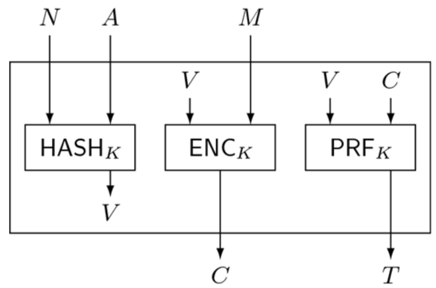
zero prepending function
zpp(N) = 0…0 || N

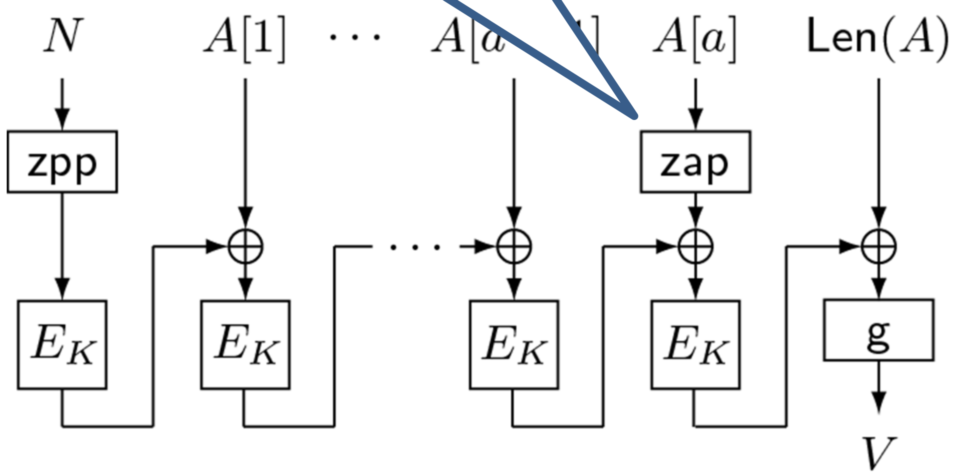


V <- HASH_K(N,A)

- variant of CBC MAC
- N: n
-

zero appending function
zap(X) = X || 0…0
(possibly none)

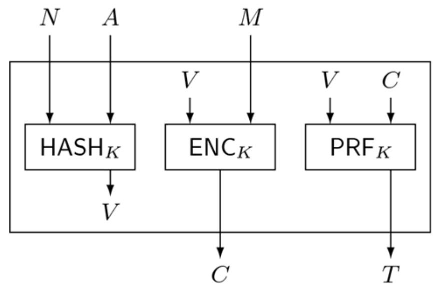


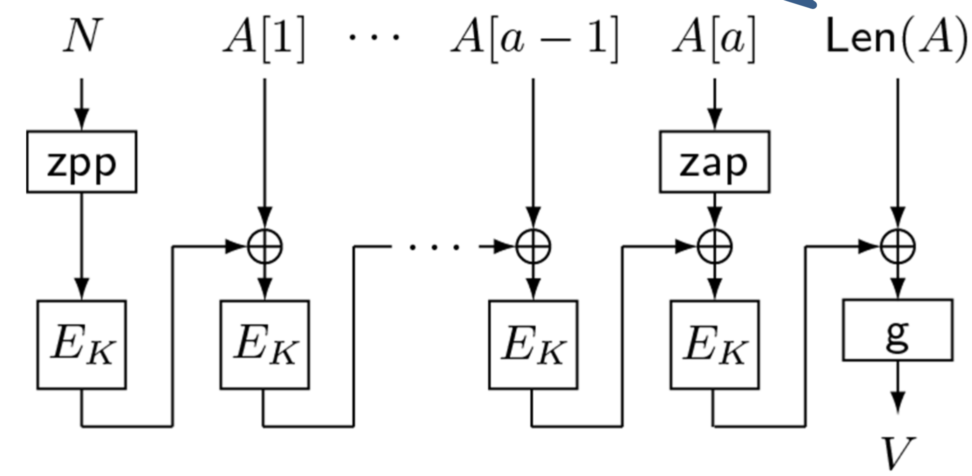


V <- HASH_K(N,A)

- variant of CBC MAC
- N: no
-

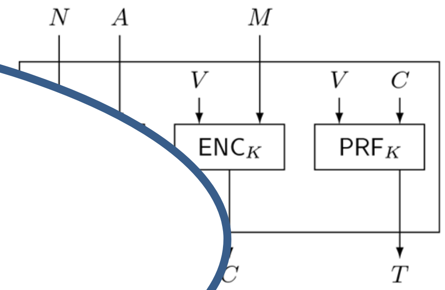
Len(A) = length of A in bytes



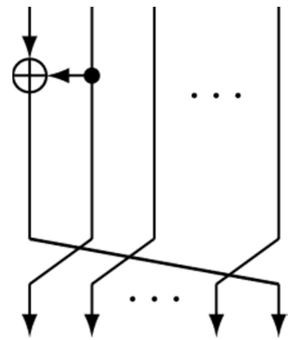


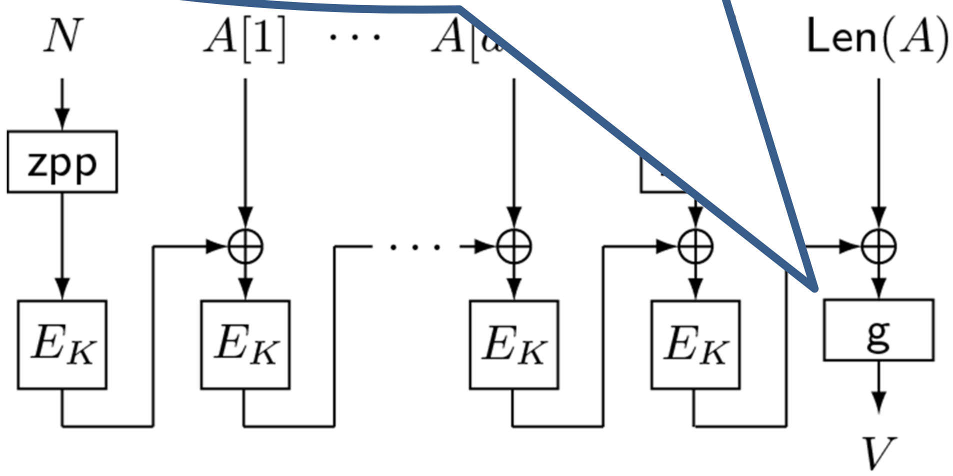
V <- HASH_K(N,A)

- variant of C…
- N:
-



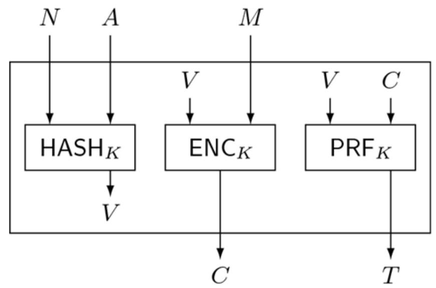
tweak function
broken into bytes

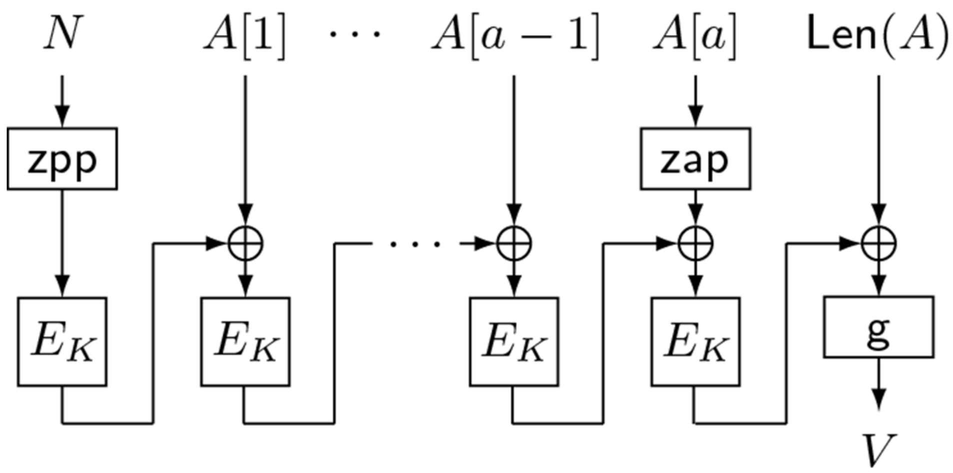




V <- $HASH_K(N,A)$

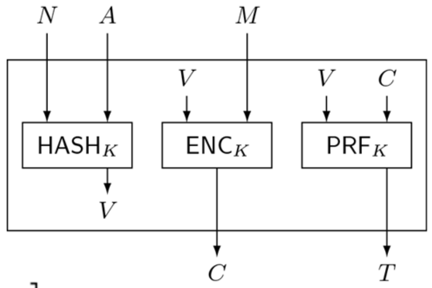
- variant of CBC MAC
- N: nonce, fixed length, $1 \leqq |N| \leqq n-1$
- A: associated data, at most $2^{n/2}$-1 bytes

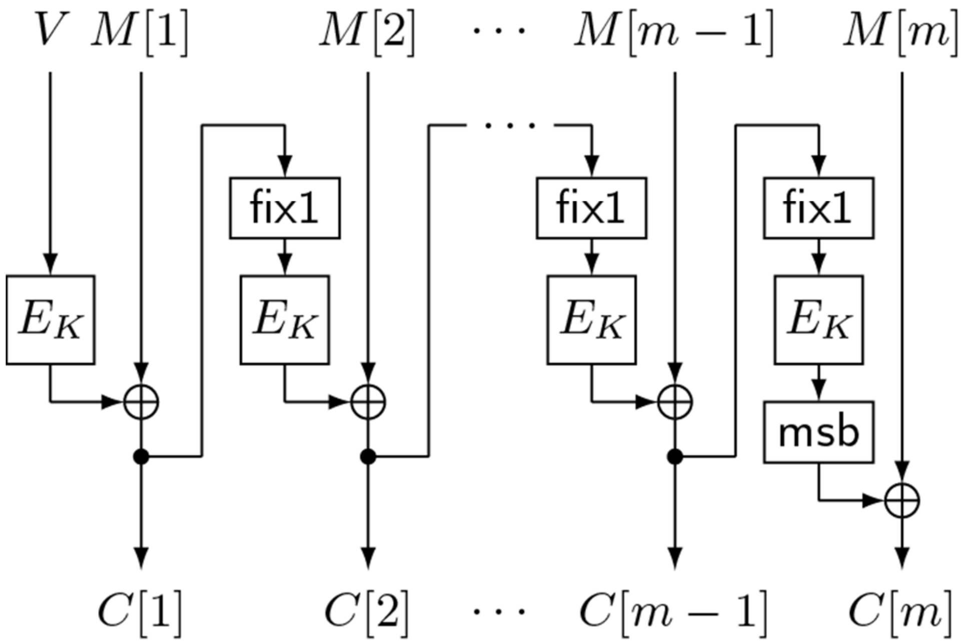




C <- ENC$_K$(V,M)

- variant of CFB mode
- M: plaintext, at most $2^{n/2}$-1 bytes

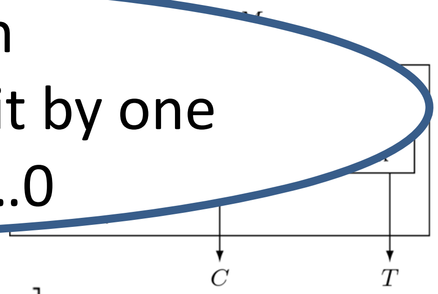


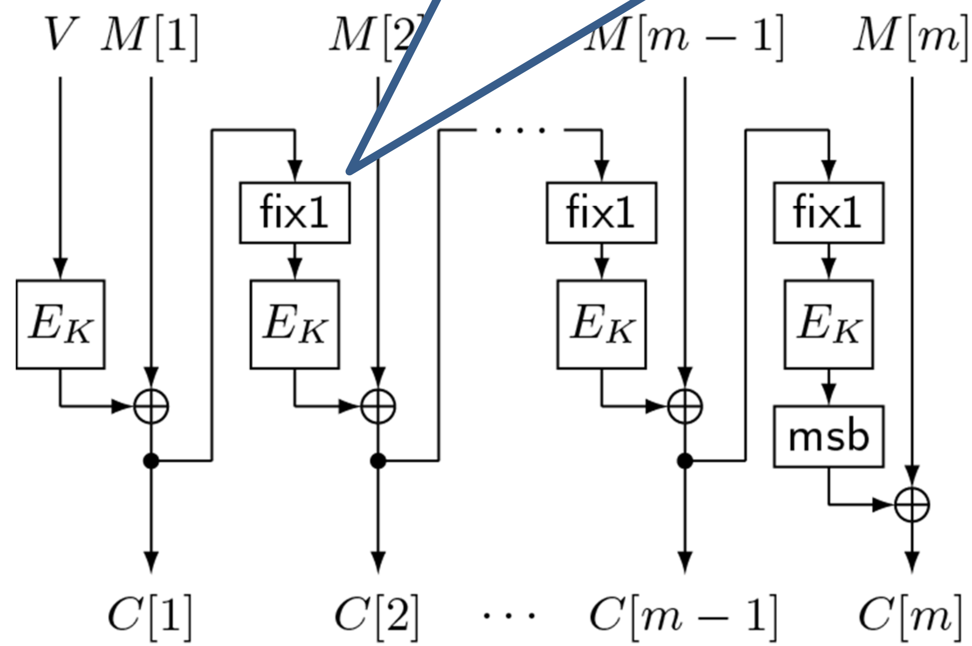


C <- ENC_K(V,M)

- variant of CFB m
- M: plaintext, a

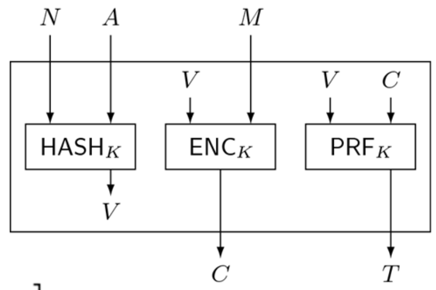
bit fixing function
fix the most significant bit by one
fix1(X) = X OR 10…0

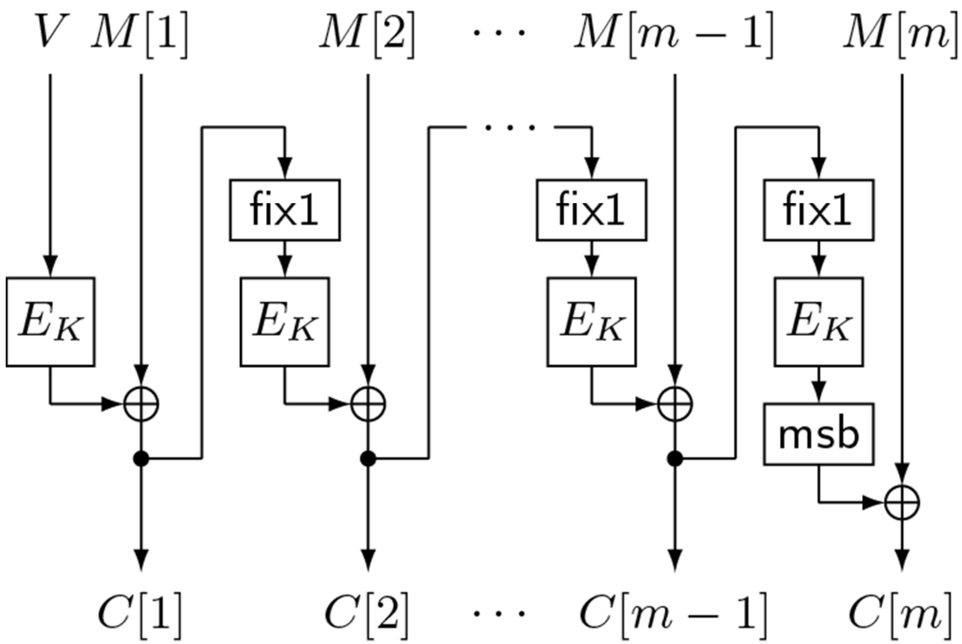




C <- $ENC_K(V,M)$

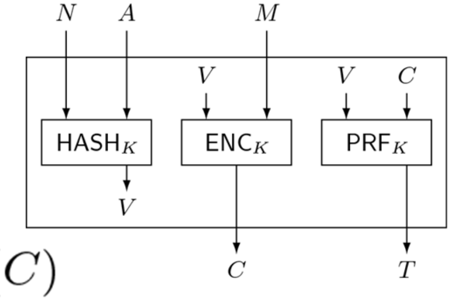
- variant of CFB mode
- M: plaintext, at most $2^{n/2}$-1 bytes

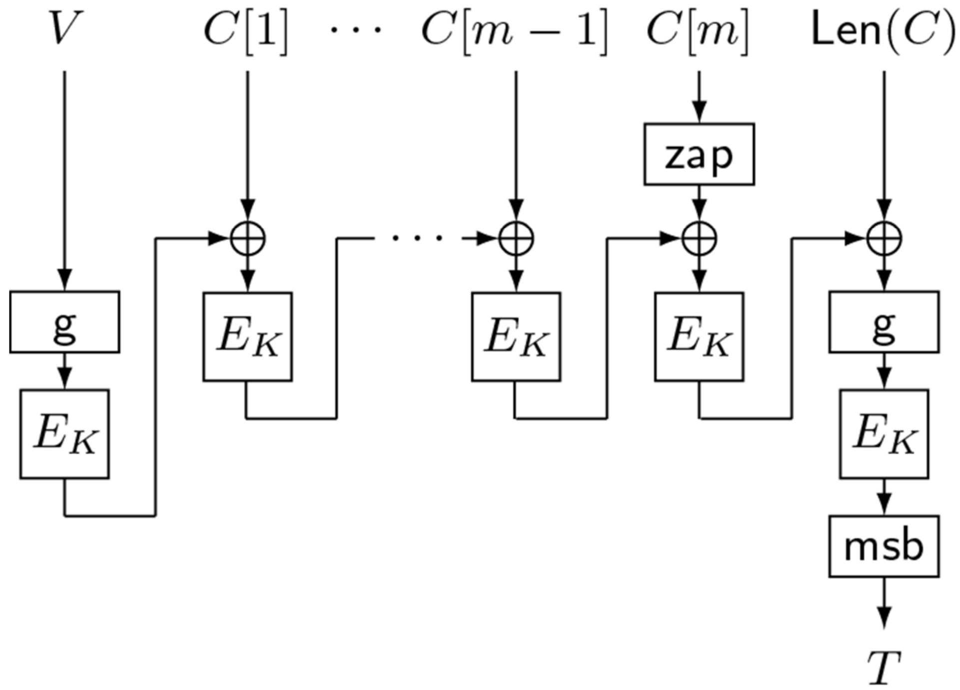




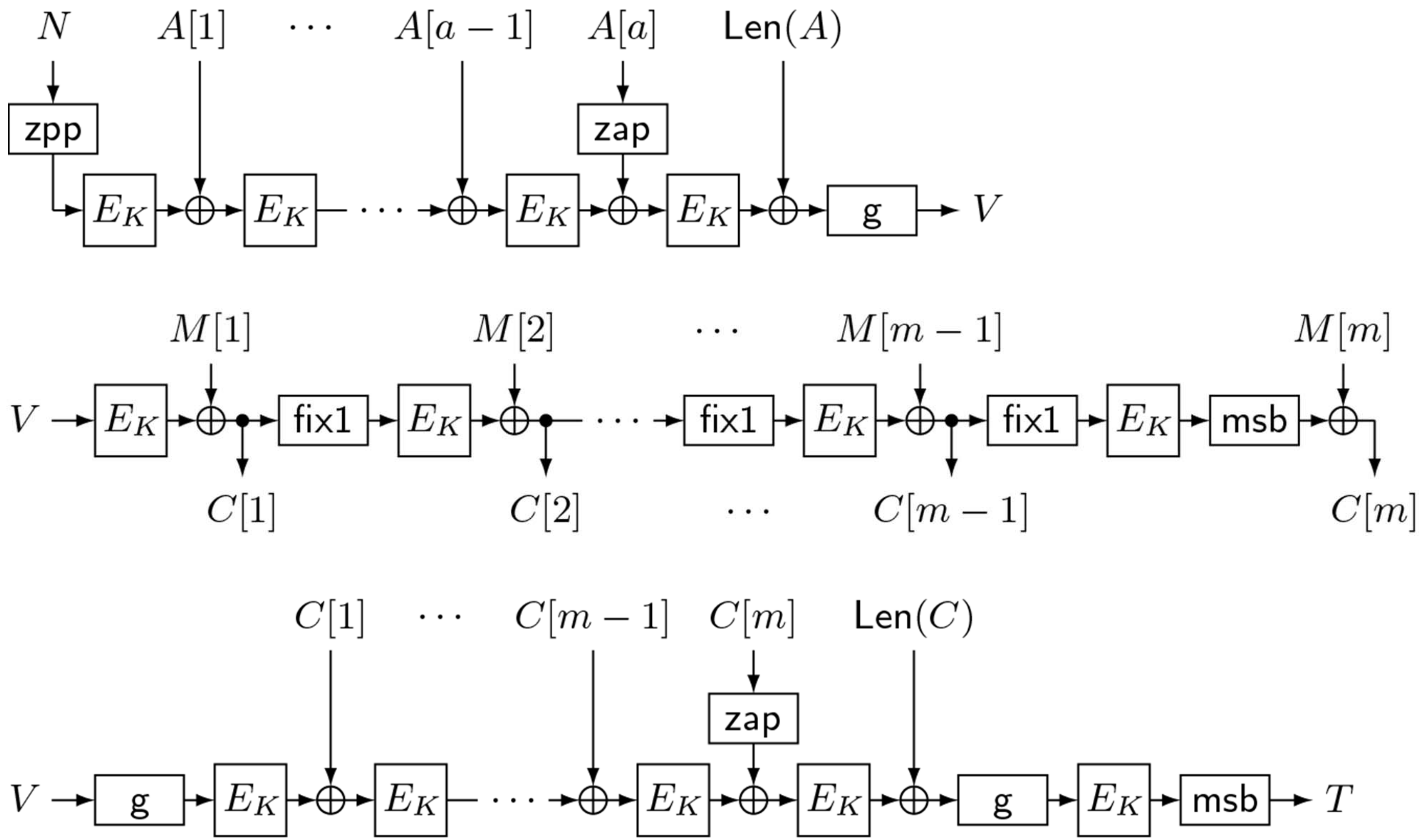
T <- $PRF_K(V,C)$

- variant of CBC MAC





Works with Two State Blocks



SILC Properties

- Nonce-based AEAD
- uses only the encryption of the blockcipher both for encryption and decryption
- It makes $|N|_n + |A|_n + 2|M|_n + 2$ blockcipher calls for a nonce N, associated data A, and a plaintext M
  - where $|X|_n$ is the length of X in n-bit blocks
  - $1 \leqq |N| \leqq n-1$, so $|N|_n = 1$
  - blockcipher key scheduling can be precomputed
  - No precomputation beyond that (blockcipher calls, generation of key dependent tables, . . .) is needed

Limitations

- Static associated data cannot be handled efficiently
  - nonce is processed before associated data
- For long plaintexts, it needs 2 blockcipher calls per one block
- HASH, ENC, and PRF are all sequential
  - blockcipher calls in ENC and PRF are parallelizable

Security

- Privacy:

  Indistinguishability of ciphertexts from random bits against nonce-respecting adversaries in a chosen plaintext attack setting

- $\mathbf{Adv}^{\mathrm{priv}}_{\mathrm{SILC}[E,\ell_N,\tau]}(\mathcal{A}) \stackrel{\mathrm{def}}{=} \Pr\left[\mathcal{A}^{\mathrm{SILC}\text{-}\mathcal{E}_K(\cdot,\cdot,\cdot)} \Rightarrow 1\right] - \Pr\left[\mathcal{A}^{\$(\cdot,\cdot,\cdot)} \Rightarrow 1\right]$

- $\mathbf{Adv}^{\mathrm{priv}}_{\mathrm{SILC}[\mathrm{Perm}(n),\ell_N,\tau]}(\mathcal{A}) \leq \dfrac{5\sigma^2_{\mathrm{priv}}}{2^n}$, where $\sigma_{\mathrm{priv}} = 3q + \sigma_A + 2\sigma_M$

Security

- Authenticity:

  Unforgeability against **nonce-reusing** adversaries in a chosen ciphertext attack setting

- $\mathbf{Adv}^{\mathrm{auth}}_{\mathrm{SILC}[E,\ell_N,\tau]}(\mathcal{A}) \stackrel{\mathrm{def}}{=} \Pr\left[\mathcal{A}^{\mathrm{SILC}\text{-}\mathcal{E}_K(\cdot,\cdot,\cdot),\mathrm{SILC}\text{-}\mathcal{D}_K(\cdot,\cdot,\cdot,\cdot)} \text{ forges}\right]$

- $\mathbf{Adv}^{\mathrm{auth}}_{\mathrm{SILC}[\mathrm{Perm}(n),\ell_N,\tau]}(\mathcal{A}) \le \dfrac{5\sigma^2_{\mathrm{auth}}}{2^n} + \dfrac{q'}{2^\tau},$

  where $\sigma_{\mathrm{auth}} = 3q + \sigma_A + 2\sigma_M + 3q' + \sigma_{A'} + \sigma_{C'}$

Security

- Authenticity:

  Unforgeability against **nonce-reusing** adversaries in a chosen ciphertext attack setting

- $\mathbf{Adv}^{\mathrm{auth}}_{\mathrm{SILC}[E,\ell_N,\tau]}(\mathcal{A}) \stackrel{\mathrm{def}}{=} \Pr\left[\mathcal{A}^{\mathrm{SILC}\text{-}\mathcal{E}_K(\cdot,\cdot,\cdot),\mathrm{SILC}\text{-}\mathcal{D}_K(\cdot,\cdot,\cdot,\cdot)} \text{ forges}\right]$

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  where $\sigma_{\mathrm{auth}} = 3q + \sigma_A + 2\sigma_M + 3q' + \sigma_{A'} + \sigma_{C'}$

- Standard birthday bounds, proofs are similar to those of CLOC

Recommended Parameter Sets

- E_K: blockcipher with an n-bit block
  - n: 64 or 128
  - AES-128 for n = 128, and PRESENT-80 or LED-80 for n = 64
- l_N: nonce length in bits
  - 96 or 64 for n = 128, and 48 for n = 64
- tau: tag length in bits
  - 64 for n = 128, and 32 for n = 64

Recommended Parameter Sets

- E_K: blockcipher with an n-bit block
  - n: 64 or 128
  - AES-128 for n = 128, and PRESENT-80 or LED-80 for n = 64
- l_N: nonce length in bits
  - 96 or 64 for n = 128, and 48 for n = 64
- tau: tag length in bits
  - 64 for n = 128, and 32 for n = 64

- 64-bit blockciphers are not for general purpose applications
  - for applications that can ensure the total amount of data processed with one key
  - low data transmission rate, limited battery lifetime

HW Implementation

- We evaluated AES-SILC for ASIC using a 90 nm standard cell library
- HW reference implementation AES-SILC
  - to see the basic performance
- Compared it with AES-CLOC, AES-OTR, and AES-EAX
  - Unit = Gate Equivalent (GE)
  - AES is round-based, where S-box uses the composite-field expression
  - single AES core

HW Implementation

- Scenario 1
  - Frequency is fixed to 100 MHz

	AES	SILC	CLOC	OTR	EAX
Gates (GE)	10207.75	15675.5	17137.75	21862.5	28662.25
Ratio (AES)	1	1.54	1.68	2.14	2.81
Throughput (Mbit/sec)	1163.63	764.12	685.71	1134.18	794.48

- SILC is the smallest (x 1.54 of AES size)
- no significant change if the freq. ~= 20 MHz
- Throughput is an estimation

HW Implementation

- Scenario 2
  - The same RTL (Register Transfer Level) as Scenario 1
  - find the maximum frequency

	SILC	CLOC	OTR	EAX
Max freq. (MHz)	344.8	312.5	333.3	277.8
Gates (GE)	23135	25287.25	29080.75	35305
Ratio (AES)	1.57	2.01	2.07	3.16
Throughput (Mbit/sec)	2634.88	2142.85	3780.21	2207.07

- Ratio: compared with AES of the corresponding freq.
- SILC is again the smallest (x 1.57 of AES size)
- Throughput is an estimation

SW Implementation

- Not the main focus of SILC
- General purpose CPU
  - Intel(R) Core(TM) i5-3427U CPU, 1.80GHz (Ivy Bridge)
  - with a long plaintext (more than 2^{20} blocks) and empty associated data, and with parallelism P

	AES-SILC	PRESENT-SILC	LED-SILC
Speed (cpb)	4.9	42	40
Remarks	AES-NI, P=1	bit-sliced, P=16	bit-sliced, P=32

- In AES-SILC, E_K in ENC and PRF are computed in parallel
- AES-CLOC: about 4.9 cpb (P = 1)
- serial AES-128 encryption: about 4.3 cpb

LED Reference Code

- Inconsistency in the description of LED in the submission document and the LED reference code
  - The LED reference code will be updated soon
  - The reference code of SILC remains unchanged

Conclusions

- Designed SILC and analyzed the security and the efficiency
- SILC is suitable for use within constrained HW devices

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