Maastricht University

Accordion Modes: Basic Idea, Known Constructions, and Recent Developments

Bart Mennink

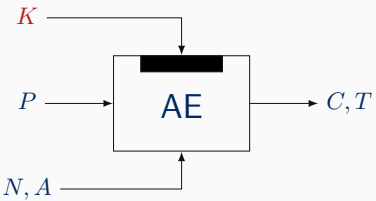
Gausta

April 14, 2026

Outline

Authenticated Encryption and GCM

Authenticated Encryption (AE): Wrap and Unwrap



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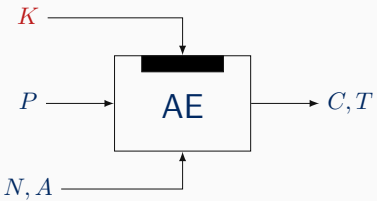

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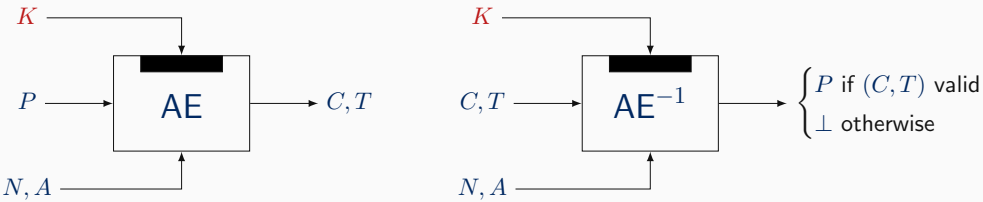

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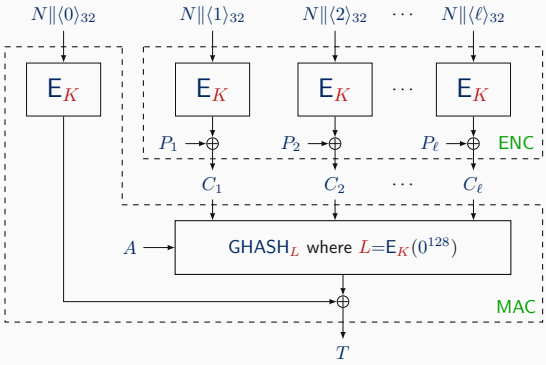
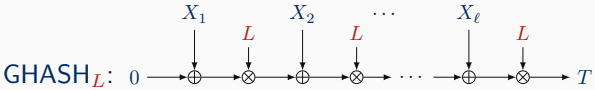
- Unwrapping needs to satisfy that
  - Plaintext P disclosed if (C, T) comes from an evaluation of wrap
  - Error symbol otherwise

GCM for 96-bit Nonce N [MV04]





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- Cooler variant: ChaCha20-Poly1305!

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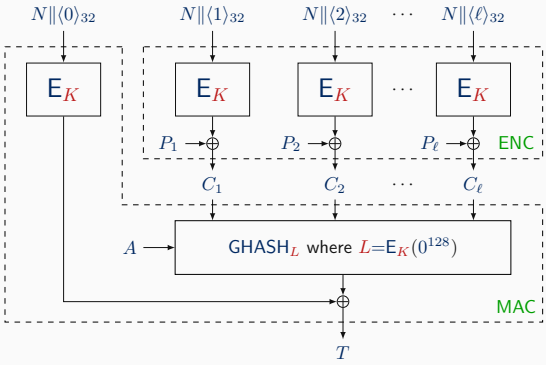

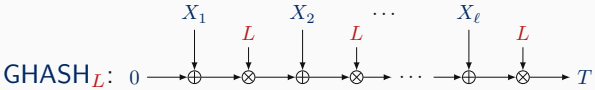

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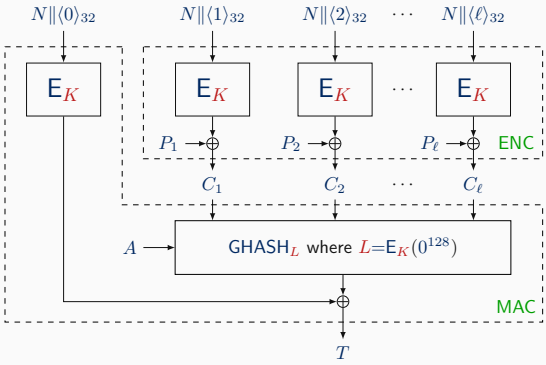

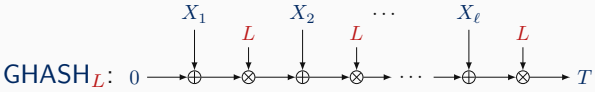

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Secure as Long as...

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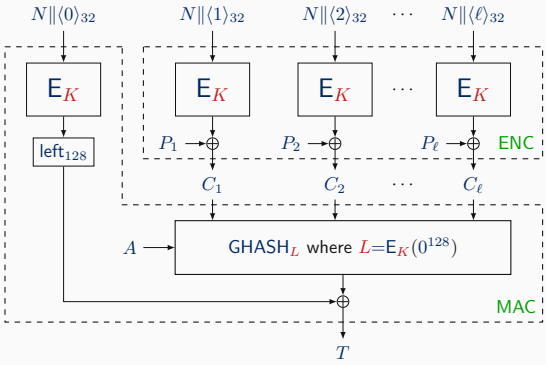
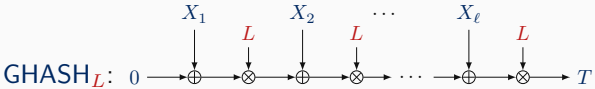
- ... but nonce reuse is devastating
  - Leaks $P \oplus P' = C \oplus C'$ and L

What Rijndael-256 Would Solve





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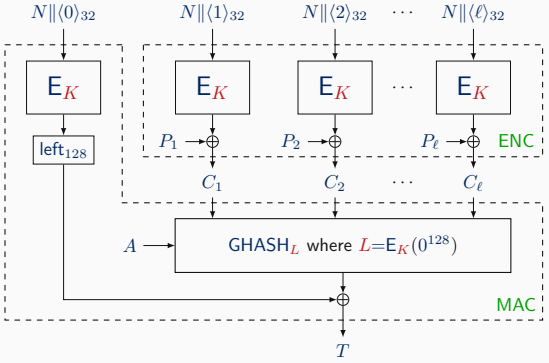

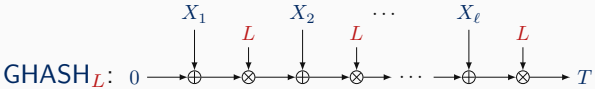

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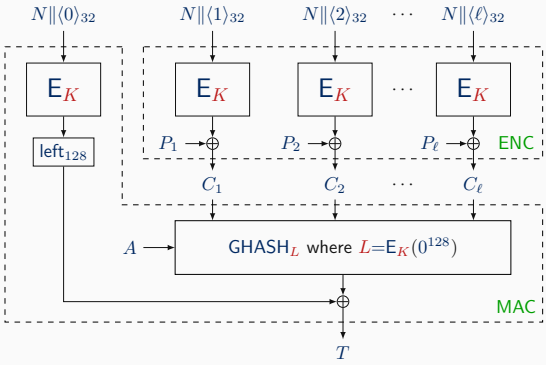

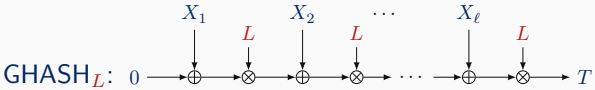

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- ... but $\mathsf{E}_K(N\|\langle 0\rangle_{32})$ outputs 256-bit subkey material
  - Use half of it as GHASH-key L
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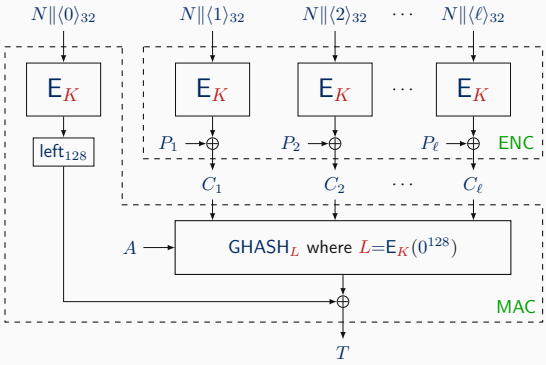

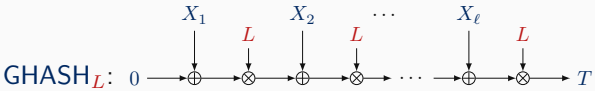

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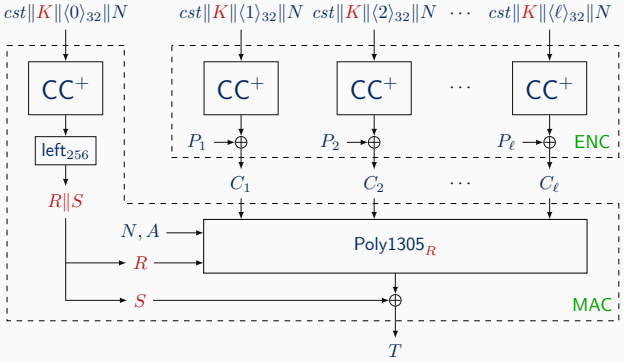
- Would give nonce misuse resilience

ChaCha20-Poly1305



- Bernstein [Ber05, Ber08]
- RFC 8439 [NL18]

- CC: 512-bit permutation
- CC$^+$: CC plus feed-forward

$$\text{Poly1305}_R(X) = (1\|X_1)\cdot R^\ell + (1\|X_2)\cdot R^{\ell-1} + \cdots + (1\|X_{\ell-1})\cdot R^2 + X_\ell \cdot R \bmod 2^{130} - 5$$

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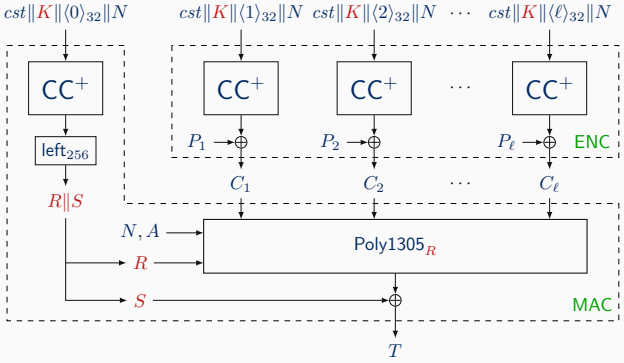

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- Both key and mask of Poly1305 are nonce-dependent

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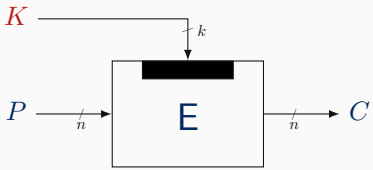
Accordion Modes

Block Ciphers



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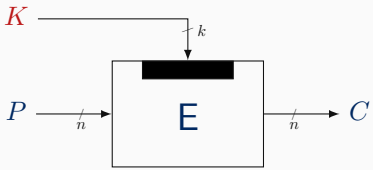

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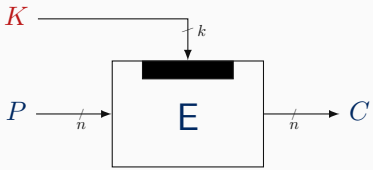
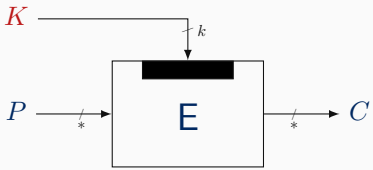


- Plaintext P is encrypted to ciphertext C using secret key K
- Fixed block size
- In order to encrypt variable sized messages, we need a mode of operation
  - These modes require a nonce

Wide Block Ciphers



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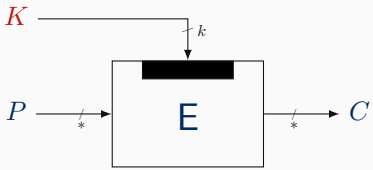

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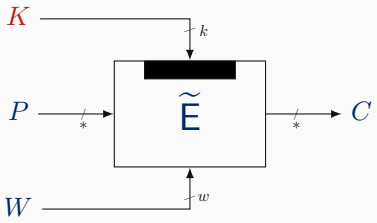
- A wide block cipher is a block cipher with a variable block size
- Every part of the output (ideally) depends on every part of the input

Tweakable Wide Block Ciphers



- A tweakable wide block cipher additionally has a tweak
- Tweak W public, ciphertext completely changes with a different tweak

NIST's Incentive to Develop Accordion Mode

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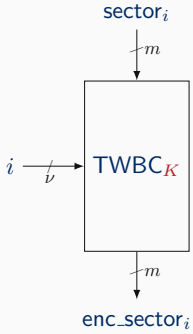
Rest of the Talk: Why? How? Really, Why?

Applications

Disk Encryption



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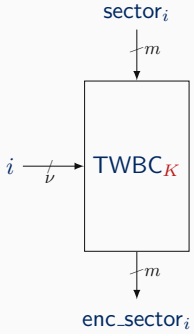

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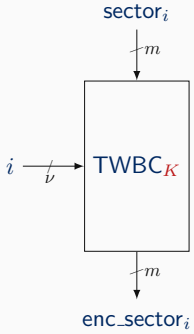

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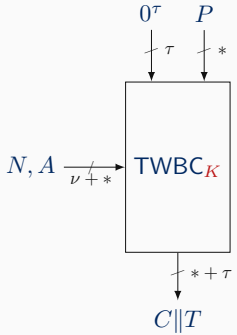
Usage

- XTS-AES is standardized as IEEE P1619 and widely used
- Android and dm-crypt support accordion mode Adiantum



Encode-Then-Encipher (ete) [BR00, HKR15]

- Encryption:
  - Prepend τ zeros to P
  - Evaluate with TWBC$_K$ to obtain $C \| T$
- Decryption:
  - Decrypt $C \| T$ using TWBC$_K^{-1}$
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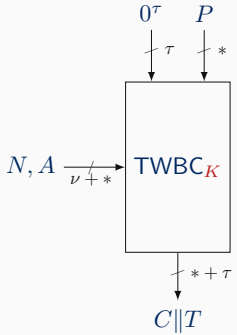
Encode-Then-Encipher from Tweakable Wide Block Ciphers



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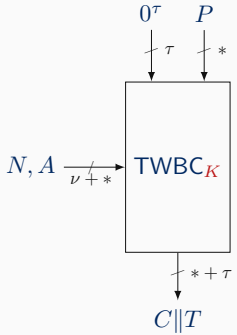

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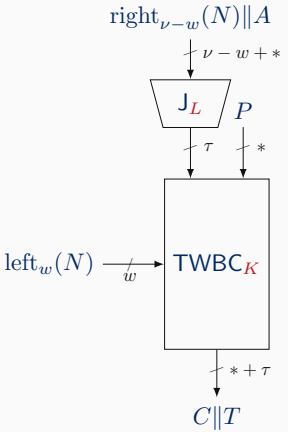
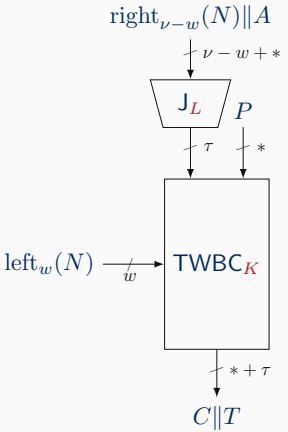


Advanced AE with AD (aaa) [DMMT25]

- TWBC_K: tweakable wide block cipher
- J_L: universal hash



Advanced AE with AD (aaa) [DMMT25]

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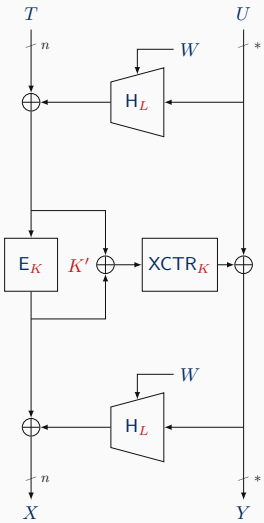
Rationale

- N partially entered into tweak
- Rest of N and A hashed into τ-bit string
- Recall: nonce reuse has limited impact

Features

- Similar to ete
- Potentially cheaper tweak processing

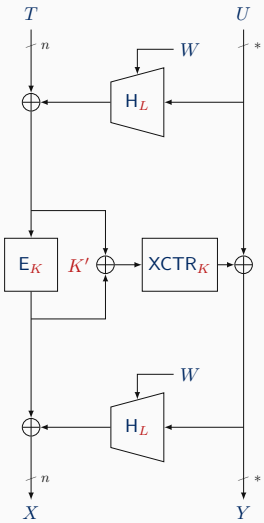
Notable Constructions



Building Blocks

- E_K: block cipher
- XCTR_K: XOR-based Counter
- H_L: universal hash

HCTR2 [CHB21]



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- Left lane of fixed size
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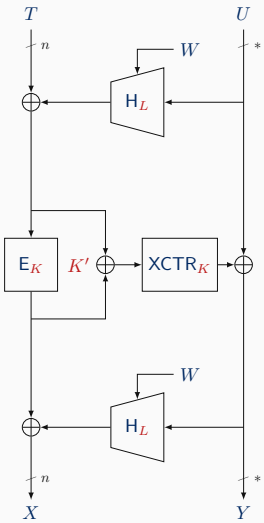

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- Supports inputs of $\geq n$ bits
- Birthday bound secure

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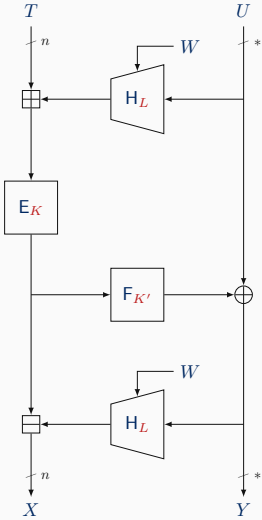

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- $\mathsf{F}_{K'}$: stream cipher
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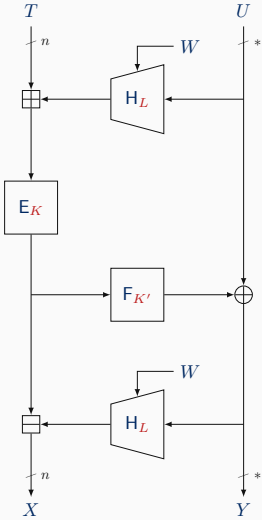

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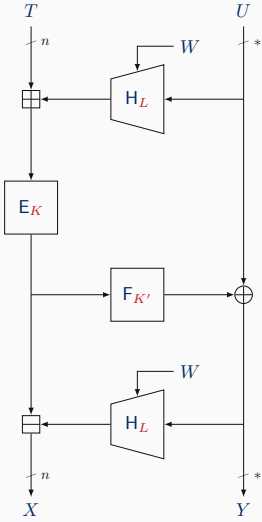
- $\mathsf{F}_{K'}$: stream cipher
- H_L: universal hash

Construction

- Inspired by HCTR2 but for cool schemes:
  - NH/Poly1305 for universal hash
  - XChaCha12 for streaming

HCTR2's Sibling Adiantum [CB18]



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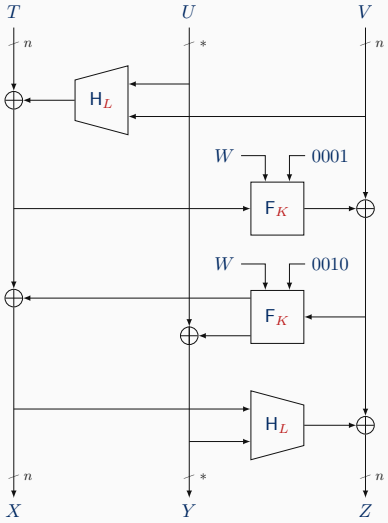
Features

- Supports inputs of $\geq n$ bits
- Birthday bound secure
- Massively used for Android device encryption

Docked Double Decker [GDM19]



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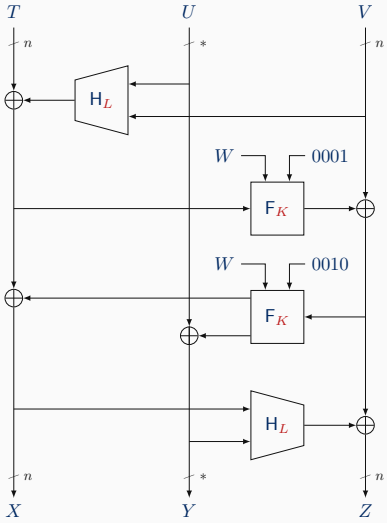

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- Inner lane of variable size

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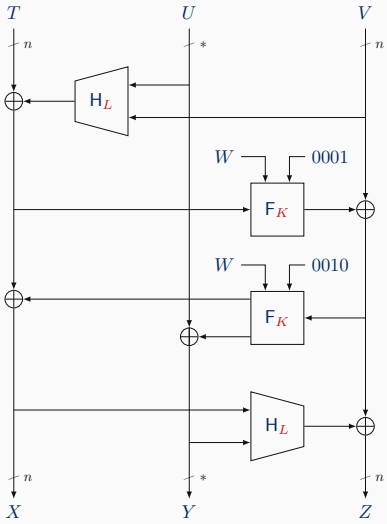


Building Blocks

- F_K: stream cipher
- H_L: universal hash

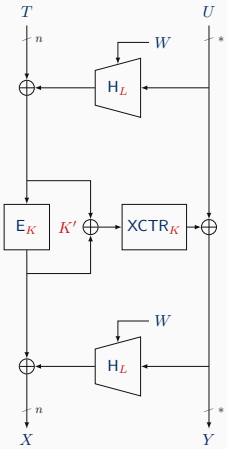
Construction

- Feistel-like structure
- Outer lanes of fixed size
- Inner lane of variable size

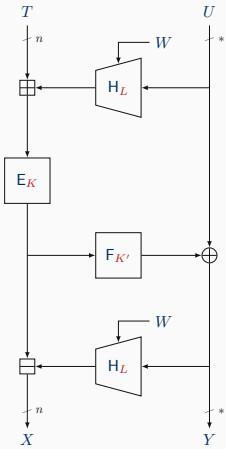
Features

- Supports inputs of $\geq 2n$ bits
- Birthday bound secure...
- ... but improved if tweaks are not reused too often

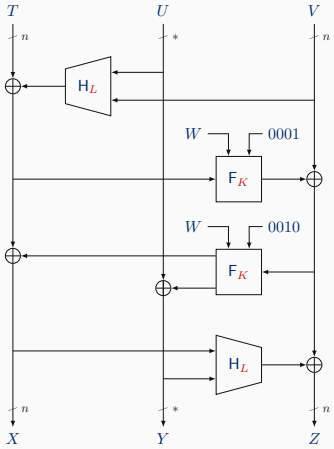
Comparison of HCTR2, Adiantum, and Docked Double Decker



HCTR2 [CHB21]



Adiantum [CB18]



Docked double decker [GDM19]

Is This Really Efficient?

Efficient Instances of Docked Double Decker With AES, and Application to Authenticated Encryption

Christoph Dobraunig[1], Krystian Matusiewicz[2], Bart Mennink[3] and Alexander Tereschenko[2]

Our Goals in [DMMT25]

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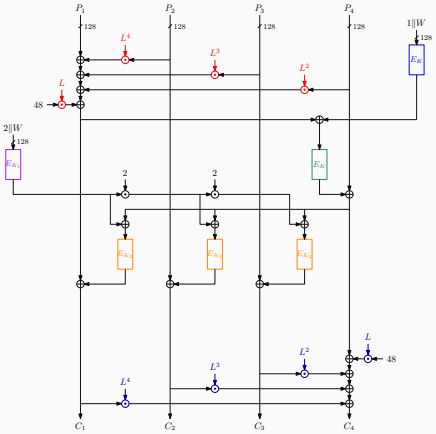
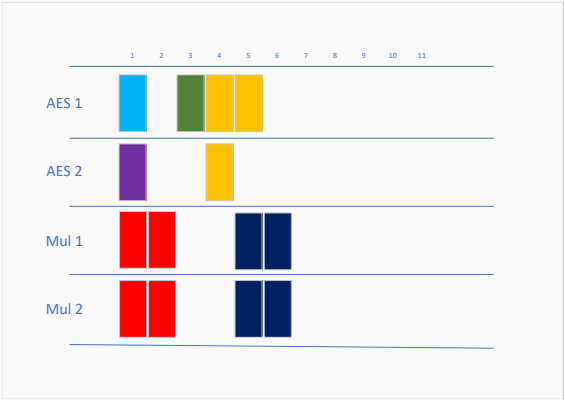
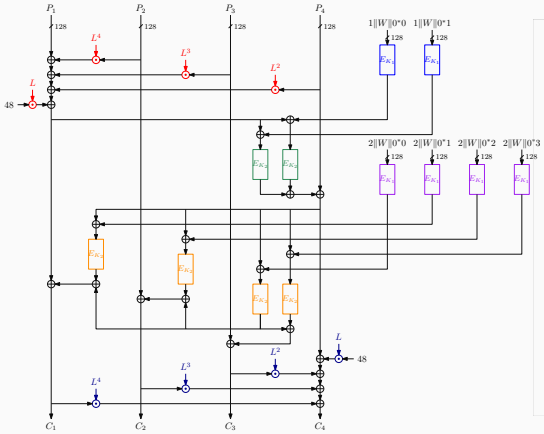
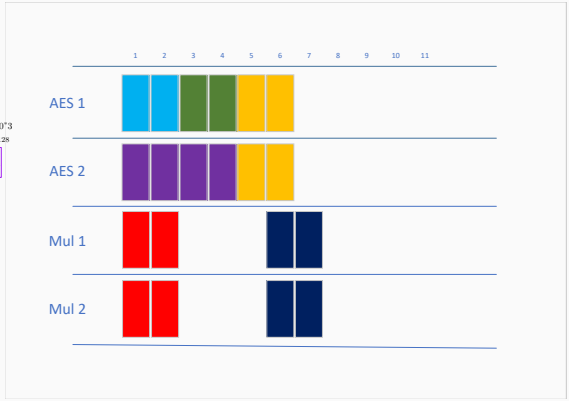
Implementation Design of $ddd\text{-}AES$ (512-Bit Message)





Implementation Design of $bbb\text{-}ddd\text{-}AES$ (512-Bit Message)





Benchmarks

- $ddd\text{-}AES$ and $bbb\text{-}ddd\text{-}AES$ on an Intel® Core™ i7-10610U
- C implementation using AES-NI and PCLMULQDQ

Message length (bytes)	32	48	64	96	128	256	512	1024	2048
$ddd\text{-}AES$ x1	6	4.3	3.4	2.8	2.5	2.3	2.2	2.1	2.1
$ddd\text{-}AES$ x2	6	3.9	3.2	2.5	2.0	1.7	1.5	1.3	1.3
$ddd\text{-}AES$ x3	9	4.6	3.1	2.5	2.1	1.4	1.2	1.1	1.0
$ddd\text{-}AES$ x4	7	4.3	3.5	2.6	2.3	1.6	1.3	1.1	1.0
$ddd\text{-}AES$ x5	8	4.6	3.8	2.4	2.2	1.5	1.2	1.1	1.0
$ddd\text{-}AES$ x6	7	4.6	3.6	2.9	2.1	1.7	1.2	1.1	1.0
$bbb\text{-}ddd\text{-}AES$ x1	8	5.0	4.0	3.2	2.9	2.6	2.5	2.5	2.5
$bbb\text{-}ddd\text{-}AES$ x2	9	5.1	3.9	3.0	2.6	1.9	1.6	1.4	1.3
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- For comparison, CBC encryption takes ≈ 1.4 cpb for 2048 byte messages

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NIST's Plans

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- Acc256 with birthday bound security using a 256-bit block cipher
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Thank you for your attention!

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