Key Committing Security of AEZ and More

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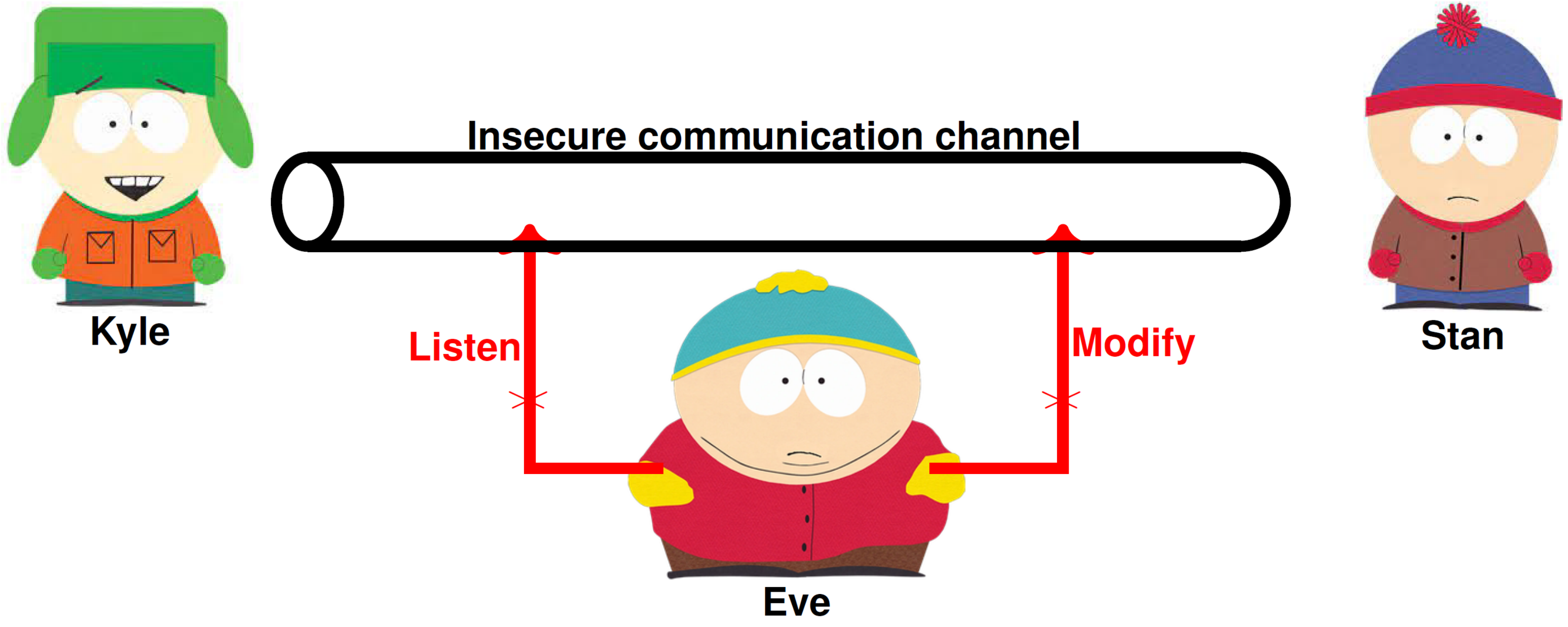
Data Confidentiality and Authenticity



- Data confidentiality
  - No outsider can learn anything about data
- Data authenticity
  - No outsider can manipulate data

Authenticated Encryption

Encryption

Decryption

Dec outputs $M = \mathrm{Dec}(N, A, C, T) \in \{0,1\}^{|C|}$ if T is correct and $\perp$ otherwise

We require that $\mathrm{Dec}_K(N, A, \mathrm{Enc}_K(A, M)) = M$

Key Committing Security

- Example: Security as proposed by Bellare and Hoang @Euro22
- Probability that an attacker can find two inputs of AE that have the same ciphertext (including tags)
  - CMT-1: different keys
  - CMT-3: different (K, N, A) pairs
  - CMT-4: different (K, N, A, M) pairs
  - CMT-3 = CMT-4 has been proven by BH22

Encode-then-Encipher via Wide-Block Cipher

- First encode the message (for example append with zeros), then apply WBC for enciphering
- Analyzing key committing security against EtE
  - WBC itself is not an AE and we need to specify where to insert 0^{τ}
- In this work, we focus on
  - AEZ: appending is specified
  - Adiantum: prepend and append with zeros
  - HCTR2: prepend and append with zeros

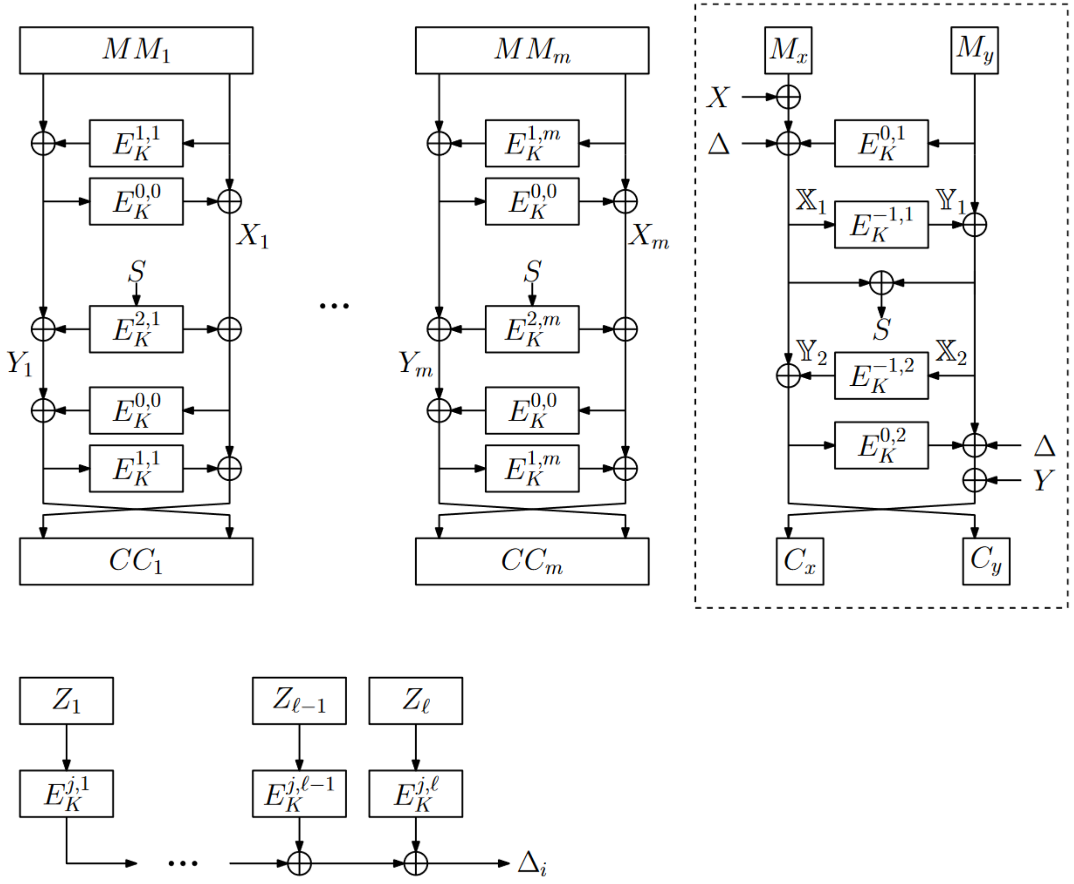
AEZ

- EtE using 128-bit TBC
  - Zero string concatenation at the end of plain text
  - Length of zero string is an arbitrary byte, not considered to exceed 128 bits
  - Input length = plaintext length + τ = ciphertext length
- Input length 256 bits or more: AEZ-core (this work!)
- Input length less than 256 bits: AEZ-tiny
  - Feistel with a minimum of 8 rounds
  - Number of steps varies depending on input length

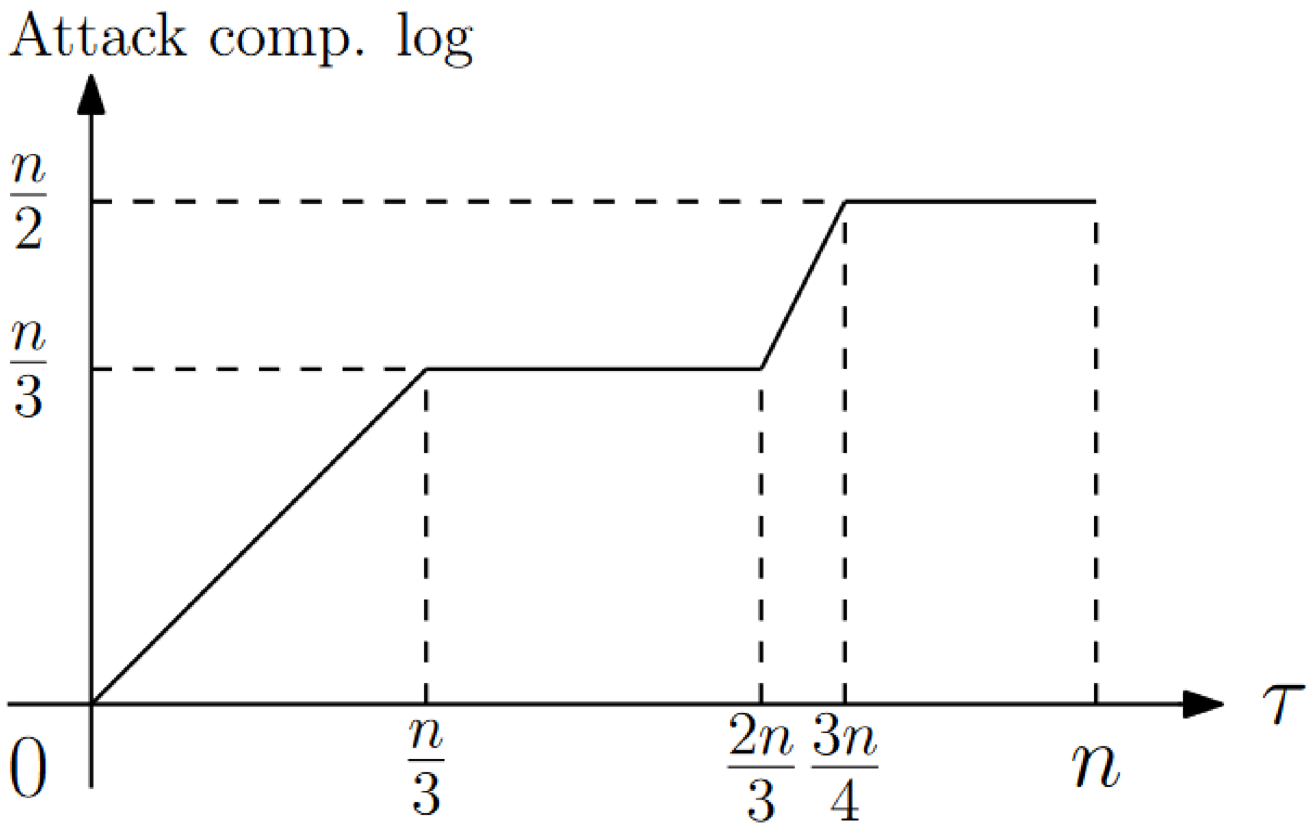
Key Committing Security of AEZ

- O(1) CMT-4 attack against general AEZ
- CMT-1 attacks
  - $\tau = n$: birthday complexity $O(2^{n/2})$
  - $\tau < n$: attack based different algorithms
  - Tightness of attack against general AEZ -> Provable security result for $\tau = n$, assuming the primitives are ideal

Collision-Finding for CMT-1 Attacks Against AEZ-Core

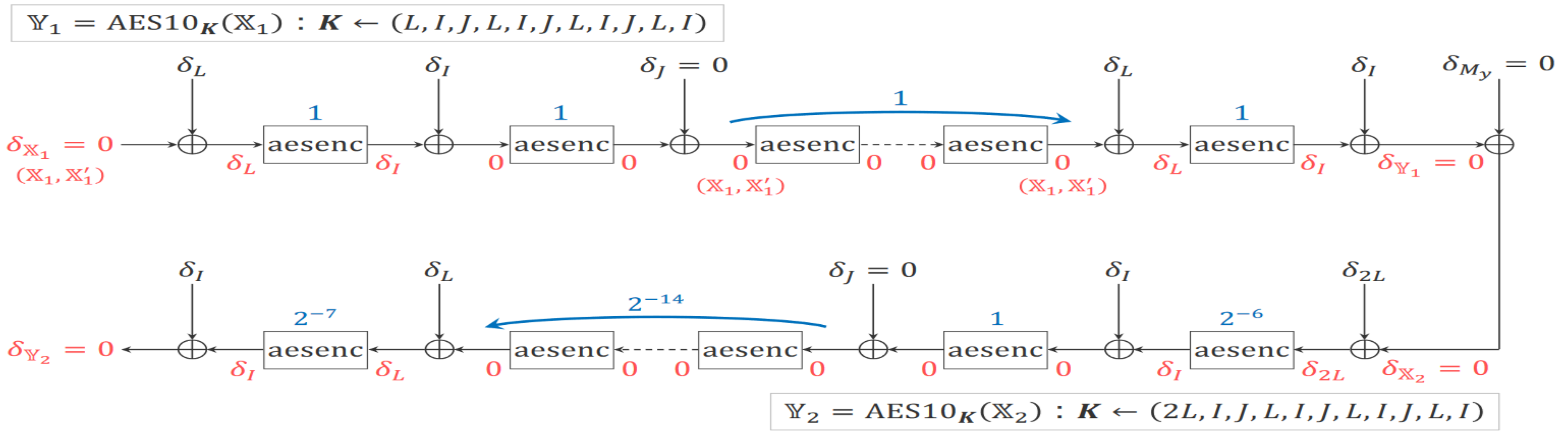


CMT-1 Attack Complexities Against gAEZ



- attack based on 4-tree algorithm, repeated 4-tree algorithm, and birthday attack

Differential Propagation in CMT-1 Attack Against Full-Spec AEZ

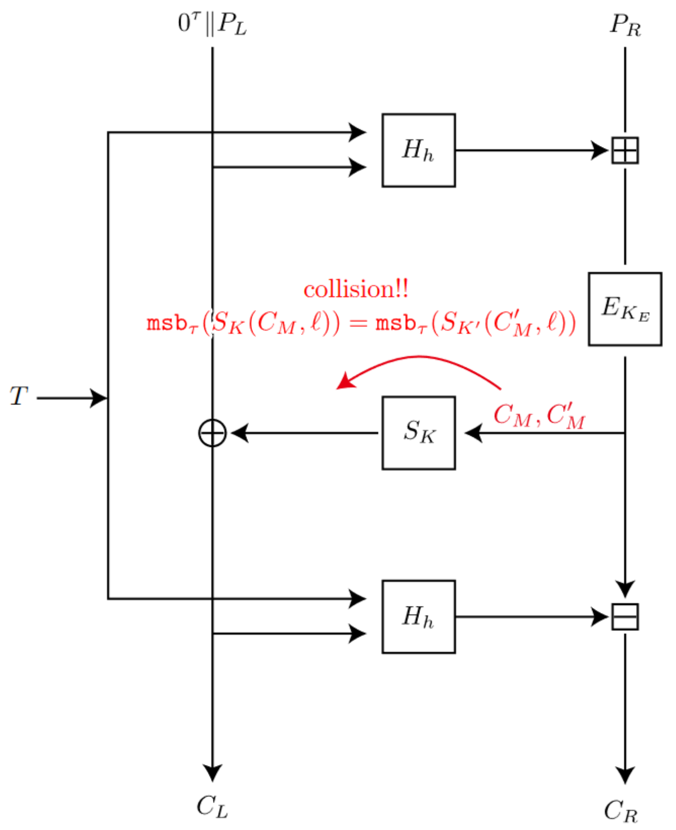


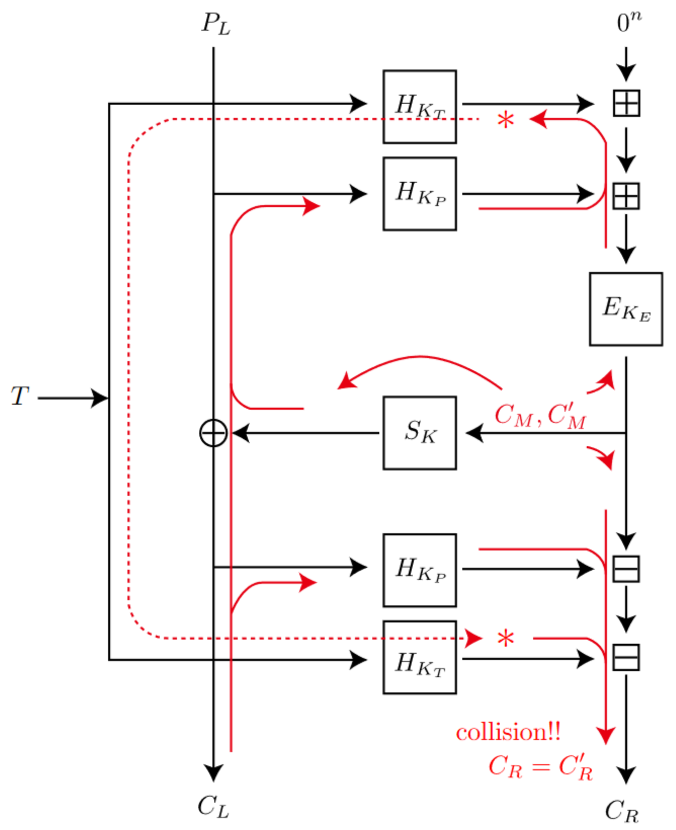
- Underlying TBC follows the full specification of AEZ-core (full-spec AEZ)
  - Choose distinct keys (K, K') -> the difference in certain intermediate states becomes 0
  - CMT-1 attack against full-spec AEZ with complexity O(2^{27})
  - A numerical example of CMT-1 attack

EtE-Adiantum

- WBC designed by Crowley and Biggers [CB18]
- Widely deployed in practice as a disk sector encryption scheme on Android devices
- NH [BHK+99] and Poly1305 [Ber05], AES-256, and XChaCha12
- Results:
  - O(1) CMT-4 attack against both prepending and appending cases
  - CMT-1 attack with birthday complexity
    - $O(2^{n/2})$ for appending case
    - $O(2^{\tau/2})$ for prepending case
    - Tightness of attack against prepending case -> provable security result assuming cryptographic permutation inside XChaCha12 is ideal
    - Using s-way collision probability of permutation-based Davies-Meyer

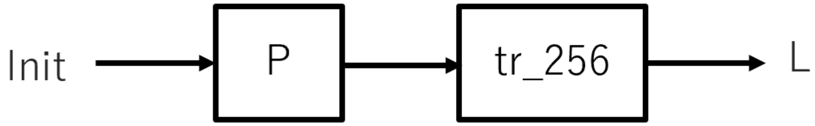
Collision-Finding for CMT-1 Attacks Against Adiantum

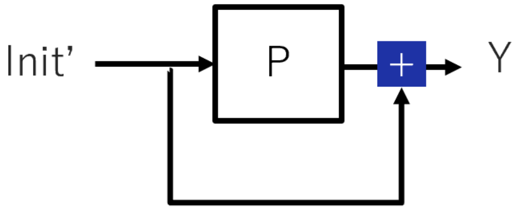




XChacha’s Block Function

- Input: key K (256 bits), nonce = (n1, n2) (128,64 bits)
- Output: Y (512 bits)
- Init = (const (128) || K (256) || n1 (128))
- P = Chacha permutation (20 rounds)
- HChacha(Init) = tr_256(P(Init) + Init)
    - “+” is 32-bit word-wise modular addition (16 additions)
    - “tr_256” concatenates the first and the last 128 bits
- Init’ = (const (128) || L (256) || 0^32 || 0^32 || n2 (64))





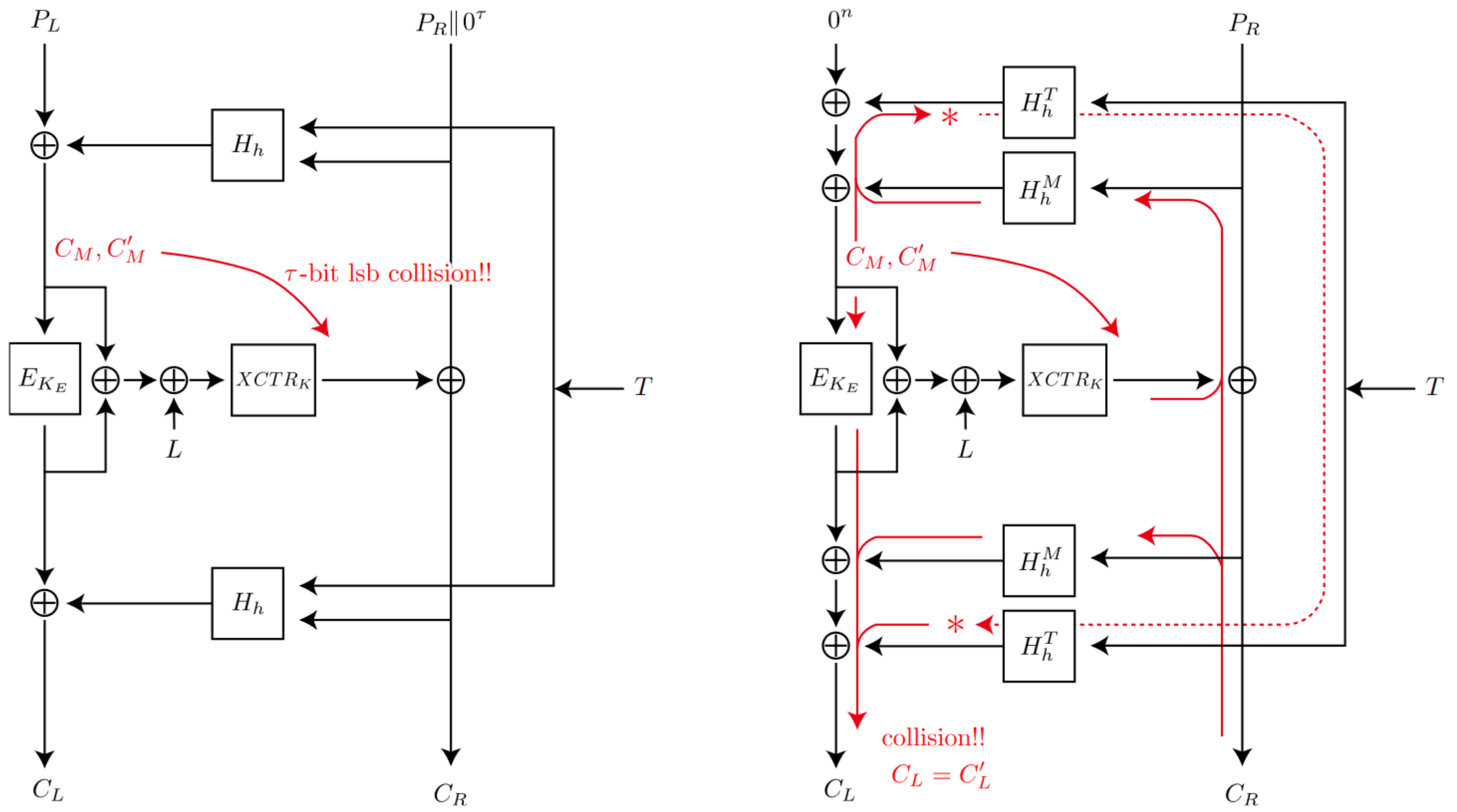
HChacha

https://datatracker.ietf.org/doc/html/draft-irtf-cfrg-xchacha-03#section-2.2

EtE-HCTR2

- WBC designed by Crowley, Huckleberry, and Biggers [CHB21]
- Based on HCTR [WFW05]
- Polynomial hash function, AES, and XCTR mode of stream encryption
- Results:
  - O(1) CMT-4 attack against both prepending and appending cases
  - CMT-1 attack with birthday complexity
    - $O(2^{\tau/2})$ for appending case
    - $O(2^{n/2})$ for prepending case

Collision-Finding for CMT-1 Attacks Against HCTR2



Summarization

Scheme	CMT-1 A	CMT-1 P	CMT-4 (A & P)	Proof
general AEZ	$O(2^{n/2})$	(not specified)	$O(1)$	$n/2$ (Sect. 7.1)
full-spec AEZ	$O(2^{27})$	(not specified)	$O(1)$	—
EtE-Adiantum	$O(2^{n/2})$	$O(2^{n/2})$	$O(1)$	$n/2$ (Sect. 7.2)
EtE-HCTR2	$O(2^{n/2})$	$O(2^{n/2})$	$O(1)$	—

Authenticated Enciphering

- Tim Beyne, Yu Long Chen, and Wonseok Choi
- An alternative definition for authenticated encryption
- Follows the work of *Mihir Bellare, Phillip Rogaway: Encode-Then-Encipher Encryption: How to Exploit Nonces or Redundancy in Plaintexts for Efficient Cryptography. (AC2000)*
- Key observation: nonce/tag pair has the same relation as the message/ciphertext pair