CTET$^+$: A Beyond-Birthday-Bound Secure Tweakable Enciphering Scheme Using a Single Pseudorandom Permutation

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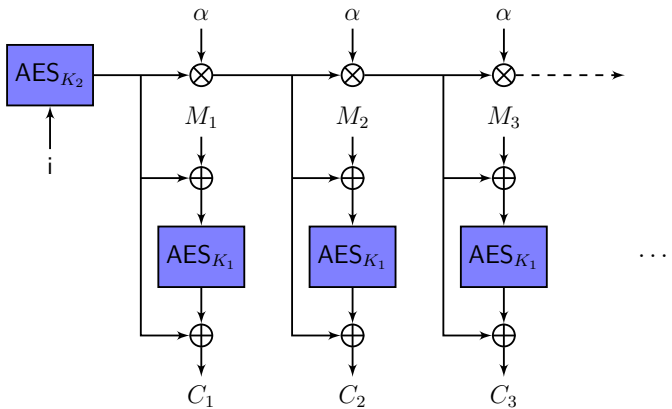
Disk Encryption

- context: encrypted data storage (full disk encryption)
- typical disk sector size: 512B to a few KB
- problem: no room to store additional data (nonce/random IVs/authentication tag)
- workaround: encrypt each sector independently

Current Standard: AES-XTS [IEE08, Dwo10]

- Tweakable mode of opertation combined with the XEX transformation for AES (security when the number of queried blocks is $\ll 2^{64}$)



- Problems: small granularity, big data centers most likely hold $> 2^{50}$ bytes

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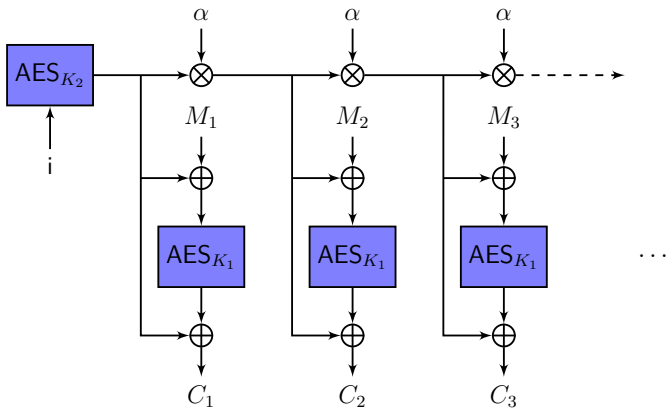

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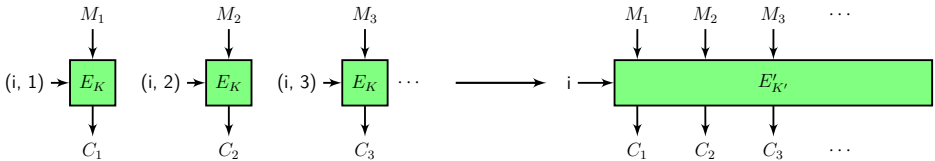
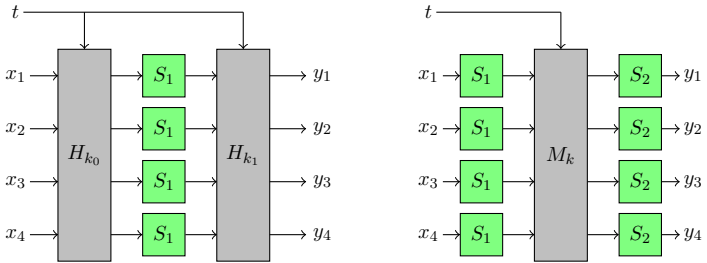
Wide Tweakable Block Ciphers

- workaround: use whole sectors as input blocks to a "wide" TBC based on a Block Cipher
- 1-bit change in $M_1 \rightarrow$ all cipher text blocks affected (solves granularity issue)

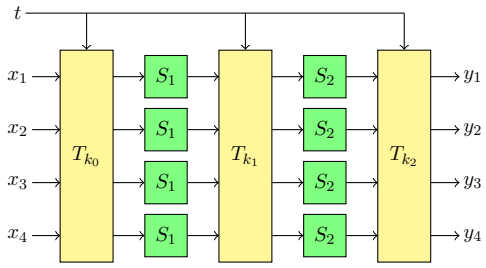


Examples



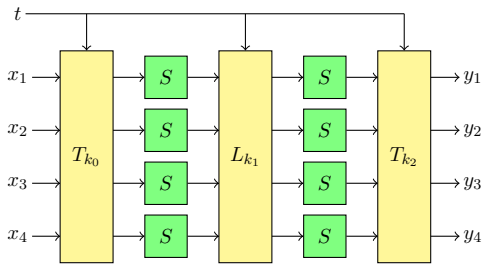
- 3 families of constructions:
  - Encrypt-Mix-Encrypt [HR03, HR04, Hal04]
  - Hash-Encrypt-Hash [CS06b, Hal07]
  - Hash-Counter-Hash [WFW05, CS06a, FM07]
- require either ≈ 2 AES calls, or ≈ 1 AES call and 2 field multiplications per block
- secure up to 2^{64} queries (Beyond Birthday Bound security $\rightarrow$ more layers)

2-Round SPN as a Tweakable Domain Extender for Block Ciphers



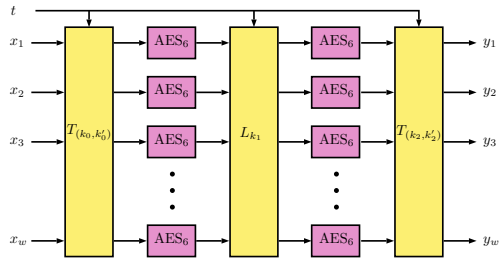
- Hash-Encrypt-Hash-Encrypt-Hash paradigm
- Secure up to $2^{2n/3}$ queries as long as T and T^{-1} are almost Super-Blockwise-Universal and Uniform (SBU) [CDK+18]

CTET$^+$



- Optimisation of the 2-round SPN: same permutation, more efficient middle layer (1 field multiplication per block $\rightarrow$ 1 doubling per block).
- secure up to $2^{2n/3}$ queries as long as T and T^{-1} are SBU

AES_6-CTET+



- block x_i, tweak t of 128 bits
- $T_{(k_0,k_0')}$ and $T_{(k_2,k_2')}$, L_{k_1}
- "*AES-box*": 6 rounds of AES-128 with a secret key
- claim: 127-bit of security

total: 5×128-bit key $(k_0, k_0'), k_1, (k_2, k_2')$ for the 3 affine layers, 128-bit key for the AES-box

Security Analysis

Our **security proof** justifies the fact that the generic structure of $\mathrm{AES}_6-\mathrm{CTET}+$ is sound, and will resist generic attacks with high probability

- H-coefficients technique

We need **dedicated cryptanalysis** to justify our security claims when the Sbox is 6 rounds of AES

- Exploit weakness of AES and extend it to full construction (AES's strength)
- Structural attacks: yoyo technique,truncated differentials

Conclusion

Scheme	Key size	Security	Efficiency (cycles/byte)		References
			512 bytes	4096 bytes	
XTS	2κ	$n/2$	0.80	0.66	[IEE08, Dwo10]
EME	κ	$n/2$	1.66	1.50	[HR04]
XCB	κ	$n/2$	1.40	1.15	[FM07]
TET	2κ	$n/2$	1.49	1.47	[Hal07]
AES_6-CDK	$6n$	$2n/3$	1.91	1.83	[CDK^+18]
AES_6-CTET^+	$5n + \kappa$	$2n/3$	1.55	1.46	This work
AES-CTET^+			2.32	2.22	

Thank you for your attention!

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References I


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CTET+ construction

$$T_{k,k'}(t,x) = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_w \end{bmatrix} \oplus \left\langle \begin{bmatrix} k \\ k^2 \\ \vdots \\ k^w \end{bmatrix}, \begin{bmatrix} x_1 \oplus t \\ x_2 \oplus t \\ \vdots \\ x_w \oplus t \end{bmatrix} \right\rangle \begin{bmatrix} 1 \\ 1 \\ \vdots \\ 1 \end{bmatrix} \oplus \begin{bmatrix} k' \\ \alpha k' \\ \vdots \\ \alpha^{w-1} k' \end{bmatrix}$$

$$L_k(t,x) = \begin{bmatrix} 3 & 2 & & 2 \\ 2 & 3 & & 2 \\ & & \ddots & \\ 2 & 2 & & 3 \end{bmatrix} x \oplus \begin{bmatrix} t \\ t \\ \vdots \\ t \end{bmatrix} \oplus \begin{bmatrix} k' \\ \alpha k' \\ \vdots \\ \alpha^{w-1} k' \end{bmatrix}$$