Tweakable Block Cipher Based Cryptography

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Outline

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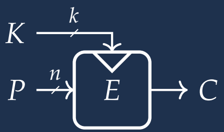
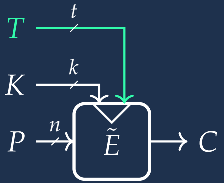
1. Introduction
2. Tweakable Block Ciphers Designs
   - Block Cipher-Based TBC
   - Ad-hoc TBC Constructions
3. Tweakable Block Ciphers for AE
4. TBC for Side-Channels Protection
   - Leakage Resilience and Protected Implementations
5. Conclusion

(Tweakable) Block Ciphers

A **block cipher** (BC) is a family of permutations parametrized by a secret key K



A **tweakable block cipher** (TBC) is a family of permutations parametrized by a secret key K and a public **tweak value** T



We denote

- P the n-bit plaintext
- C the n-bit ciphertext
- K the k-bit key
- T the t-bit tweak

(Tweakable) Block Ciphers

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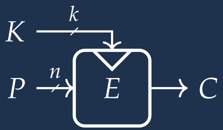

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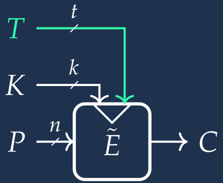
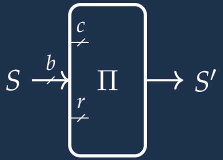


A **permutation** on $b = c + r$ bits, where c is the capacity and r is the rate (sponge framework [BDPV-07])



TBC History : Hasty Pudding Cipher

Some history : first tweakable block ciphers

Hasty Pudding Cipher from Schroeppel [Schroeppel-99]

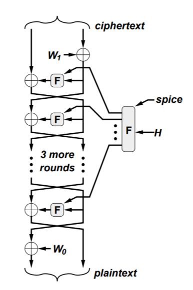
- AES competition candidate
- introduces a 512-bit "*spice*" as a "*secondary key, maybe completely or partially concealed, or completely open*" and notes that "*the spice can be changed very cheaply for each block encrypted*". It is "*expected to be changed often, perhaps for every encrypted block (allows the primary key to have a long lifetime)*"
- spice material is added to the cipher internal state every round
- **no claim against "*chosen spice attack*"**

TBC History : Mercy

Some history : first tweakable block ciphers

Mercy cipher from Crowley [Cro-FSE00]

- includes a 128-bit randomizer or "*spice*" (for disk sector encryption : sector number would be used as a tweak)
- *"The spice goes through a spice-scheduling procedure, analogous with key scheduling [...] this forms six 128-bit round spices"*
- claims about TBC security for encryption only
- broken [Flu-FSE01]



(picture from [Cro-FSE00])

TBC History : formalisation

Some history : first formalisation and generic constructions

Liskov et al. [LRW-C02] introduce first formalisation of TBC :

- *"we expect tweaks to be changed frequently, so a tweakable block cipher should have the property that changing the tweak should be efficient.* [...] *And, for any tweakable block cipher, changing the tweak should be less costly than changing the key."*.
- *"even if an adversary has control of the tweak input, we want the tweakable block cipher to remain secure"*
- introduces the two **first BC-based generic TBC constructions** `LRW1` and `LRW2`
- introduces new **TBC-based modes**, notably the **hash function** `TCH` (broken for certain instantiations [BCS-EC05]) and the **AE mode** `TAE`

Applications of TBCs

Some applications :

- many BC operating modes can be seen as TBC modes (using `XEX` construction). Ex : `PMAC`, `OCB` [Rog-AC04]
- `XTS` disk encryption mode = `XEX` + Ciphertext Stealing

Is that all ?

No, TBCs are very interesting primitives to provide **efficient**, **highly secure**, **simple** (to understand and to prove) **operating modes**, for most classical symmetric-key security notions.

Standardization effort :

- `XTS-AES` is IEEE P1619 standard (2007), NIST SP 800-38E (2010)
- `Deoxys` and `SKINNY` Committee Draft stage at ISO (18033-7)

Outline

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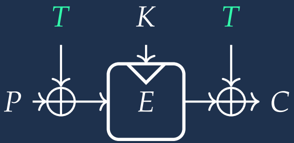
Building a TBC from a BC

A first (bad) idea

Masking input/output with a tweak (DESX-like) :

$$\tilde{E}_K(T, P) = E_K(P \oplus T) \oplus T$$



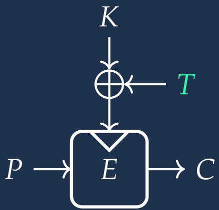
$\rightarrow$ results in an undesirable property

$$\tilde{E}_K(T, P) \oplus \tilde{E}_K(T \oplus \delta, P \oplus \delta) = \delta$$

A second (bad) idea

XORing a tweak into the key input :

$$\tilde{E}_K(T, P) = E_{K \oplus T}(P)$$



$\rightarrow$ results in an undesirable property

$$\tilde{E}_K(T, P) = \tilde{E}_{K \oplus \delta}(T \oplus \delta, P)$$

BC-based TBC : LRW1 and LRW2

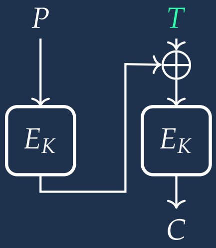
Block-cipher based TBC : LRW1 and LRW2

First BC-based constructions [LRW-C02], up to birthday bound, changing tweak hopefully cheaper than key : `LRW1` and `LRW2`

LRW1

$$\tilde{E}_K(T, P) = E_K(T \oplus E_K(P))$$

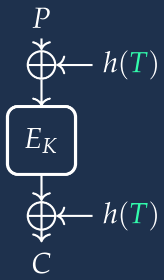
CBC-MAC



LRW2

$$\tilde{E}_{K,h}(T, P) = E_K(P \oplus h(T)) \oplus h(T)$$

h is $\oplus$-universal - part of the secret key



BC-based TBC : XE and XEX

Block-cipher based TBC : XE and XEX

XOR Encrypt (XE) - XOR Encrypt XOR (XEX) [Rog-AC04]

Idea : mask input/(output) with a key and tweak-dependant value, s.t. it is efficient if sequential tweaks $T = T'||i||j$ are used :

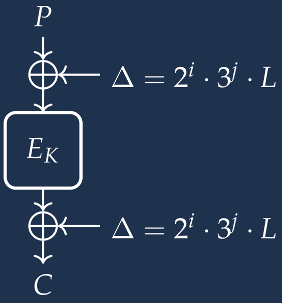
$$\tilde{E}_K(T, P) = E_K(P \oplus \Delta) \oplus \Delta$$

with $\Delta = 2^i \cdot 3^j \cdot L$ and $L = E_K(T')$

PRP/SPRP up to **birthday bound** only :

▷ collision on $P \oplus \Delta \to P \oplus P' = C \oplus C'$

▷ recover the secret L, generate forgeries



Used in :

- XTS disk encryption mode
- PMAC, OCB, about a third of all CAESAR candidates, ...

Generic TBC constructions

More generic TBC constructions and advances

- more on XEX [CS-INS06] [Min-SAC06] [CS-IT08] [GJM+-EC16]
- birthday-bound TBC from a permutation :
  TEM [STA+-14] [CLS-C15] [CS-AC15] (XEX with a permutation)
  MEM [GJM+-EC16] (TEM with more efficient masking)
  XPX [Men-C16] (improved RK security guarantees)
- beyond birthday-bound TBC constructions from BC
  [Min-FSE09] [LST-C12] [LS-FSE13] [Men-FSE15] [WGZ+-AC16]
  [JLM+-LC17] [LL-AC18]
- XTX to extend tweak size [MI-IMA15]
- adding tweak in Luby-Rackoff ciphers [GHL+-AC07]
- building a larger BC out of a TBC (for BBB security)
  [CDMS-TCC10] [Min-FSE09] [MI-IMA11] [Min-DCC15] [NI-FSE20]

Very active field, many improvements every year ...

Outline

Why ad-hoc TBC constructions ?

Why using ad-hoc TBC constructions ?

to get beyond birthday-bound security with improved efficiency !

Theoretical / ad-hoc constructions are not opposed !

We can see a lot of inspiration from ad-hoc TBCs to BC or permutation based ones and vice-versa. A lot of interplay !

How to build an ad-hoc TBC ?

The tweak schedule paradox : Tweak + Key = Tweakey

From [LRW-C02] :

- *"we expect tweaks to be changed frequently, so a tweakable block cipher should have the property that changing the tweak should be efficient. [...] And, for any tweakable block cipher, changing the tweak should be less costly than changing the key."*
- *"even if an adversary has control of the tweak input, we want the tweakable block cipher to remain secure"*

Ad-hoc TBC designer's perspective paradox :

- tweak schedule to be more efficient than the key schedule
- security requirements on the tweak *seem* somehow stronger than on the key : the attacker can fully control the former (even though tweak-recovery attacks are irrelevant)

The tweak schedule paradox : Tweak + Key = Tweakey

From [LRW-C02] :

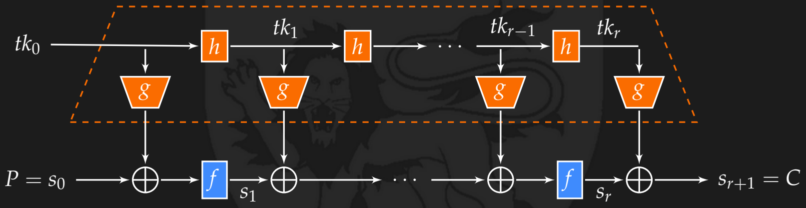
- *"we expect tweaks to be changed frequently, so a tweakable block cipher should have the property that changing the tweak should be efficient. [...] And, for any tweakable block cipher, changing the tweak should be less costly than changing the key."*
- *"even if an adversary has control of the tweak input, we want the tweakable block cipher to remain secure"*

From a designer's perspective, key and tweak should be considered as almost the same [JNP-AC14] :

Tweak + Key = Tweakey

The TWEAKEY framework

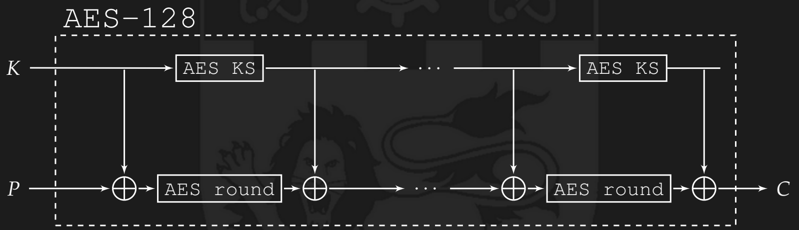
The TWEAKEY framework rationale [JNP-AC14] :
tweak and key should be treated the same way ⟶ tweakey



TWEAKEY **generalizes the class of key-alternating ciphers**

How to not tweak AES

A bad idea :
XOR 128-bit tweak value T to the internal state every round



$T =$

T_0	T_4	T_8	T_{12}
T_1	T_5	T_9	T_{13}
T_2	T_6	T_{10}	T_{14}
T_3	T_7	T_{11}	T_{15}

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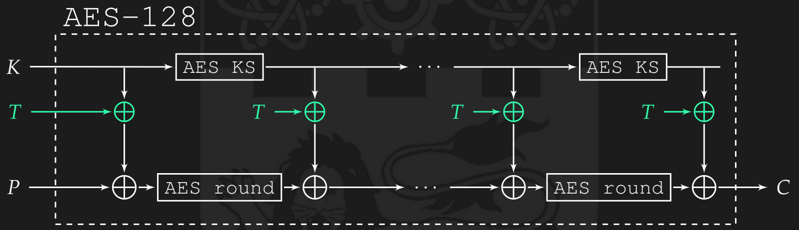

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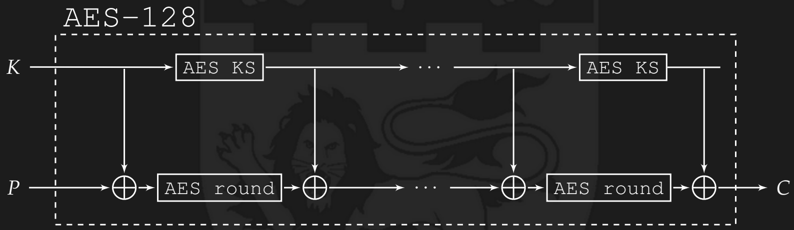
Related-tweak diff. paths with only 1 active Sbox per round

How to tweak AES : KIASU

KIASU [JNP-AC14]

Simply XORing 64-bit tweak T in the two first rows of AES internal state at every round leads to no good related-tweak differential paths



$$T = \begin{array}{|c|c|c|c|} \hline T_0 & T_2 & T_4 & T_6 \\ \hline T_1 & T_3 & T_5 & T_7 \\ \hline 0 & 0 & 0 & 0 \\ \hline 0 & 0 & 0 & 0 \\ \hline \end{array}$$

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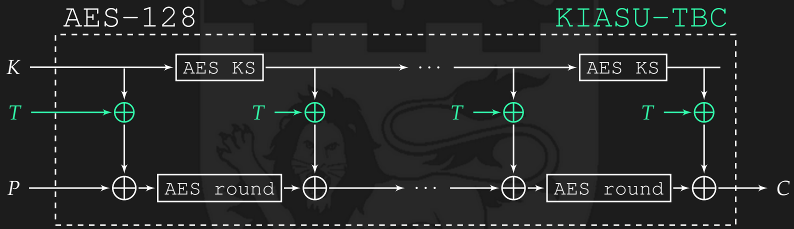

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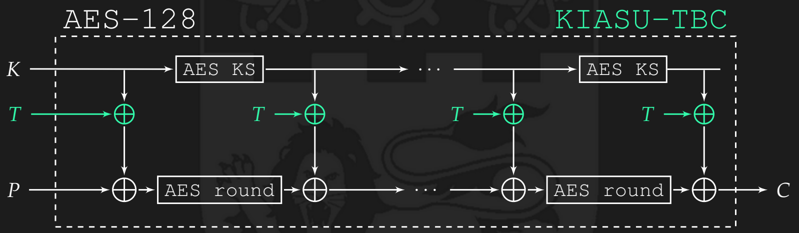


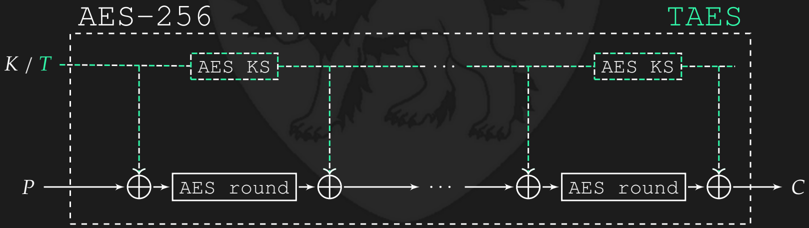
Interesting research topic :

- can an attacker leverage the freedom degrees from T ?
- what about more complex attacks ?
- so far 8 rounds can be attacked [DEM-ACNS16] [DL-CTRSA17]

Reusing existing long-key block ciphers

Idea : reuse existing long-key block ciphers

- what if we use a long-key block cipher and devote part of his key to be the tweak input ? ⚠ related-key attacks !
- **Q :** is `AES-256` with 128-bit key and 128-bit tweak a secure TBC ? Basically `TAES` proposal [BGIM-FSE20]
- **A :** not in TWEAKEY framework (RK attacks [BK-AC09]) !
- `TAES` assumes single-key scenario only, while `AES-256` RK attacks require differences in both K and T



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- TAES assumes single-key scenario only, while AES−256 RK attacks require differences in both K and T

Interesting research topic :

Are there related-key differential paths for AES−256 with only one 128-bit word active, so as to attack TAES in the single key model ?

Very short-tweak TBC

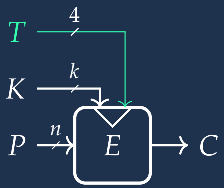
Elastic-Tweak construction for SPN ciphers [CDJ+19]

Very short-tweak TBC construction used in `ESTATE` and `LOTUS-AEAD/LOCUS-AEAD` of NIST LWC competition

Very short-tweak TBC Constructions

A very short tweak $t \ll n$ (like 4 or 8 bits) can be used :

- to simulate independent keys required by some operating modes : $E_{K_i}(P) \sim E_K(T_i, P)$
- for domain separation (full/partial block)
- not in TBC operating modes



Almost the same efficiency as the underlying BC, easy for designer because small tweak

How to build TBCs with large tweaks $t \gg n$?

How to build TBCs with large tweaks $t \gg n$?

Back to the good old problem
of key schedule design

Tweakey scheduling design

Designing a tweakey scheduling is hard :

- many many ciphers got broken in the related-key model
- ... but we have a better understanding of how to build a (twea)key schedule since the SHA−3 competition
- simplicity is an important criterion to make the analysis feasible (lack of security analysis is not allowed)
- recently automated tools (SAT, MILP, CP) are really helpful to analyse diff/linear properties of a cipher

Problem :

When t grows large, the SAT/MILP/CP problem instances becomes too large and the solvers can't handle them anymore.

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Problem :

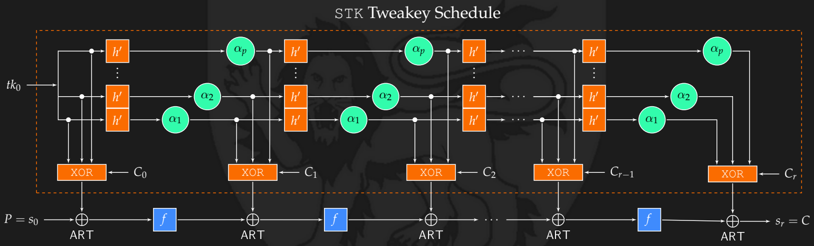
When t grows large, the SAT/MILP/CP problem instances becomes too large and the solvers can't handle them anymore.

Solution :

Create a tweakey schedule that makes it easy for the solvers!

The Superposition Tweakey (STK) construction

We can solve this problem using the Superposition Tweakey (STK) construction [JNP-AC14] :
The search problem for the tweak part is now reduced from a t-bit to a n-bit problem with a few extra cancellation conditions.



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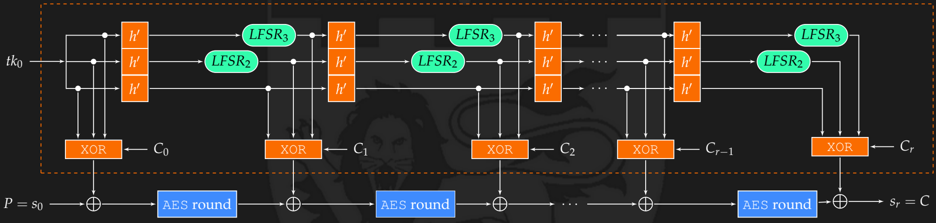
Now the goal is to find :
- ▷ cheap α_i transformations that minimize #cancellations
- ▷ best h' to maximize resistance against related-tweakey attacks

Interesting research topic :
- ▷ finding the α_i to minimize cancellations when t grows large
- ▷ maybe use an error correcting code on the tweak/key cells to generate all the successive subtweakeys ?

Deoxys-TBC

Deoxys-TBC applies this STK idea to the AES [JNP-AC14]



Comparing Deoxys-TBC and AES

Deoxys-TBC applies this STK idea to the AES [JNP-AC14]

Number of active Sboxes in single-key (SK) and related-key (RTK)

Cipher	Model	Rounds 1	2	3	4	5	6	7	8
Deoxys-TBC-256	SK	1	5	9	25	26	30	34	50
(14 rounds)	RTK	0	0	1	5	9	12	≥ 16	≥ 19
AES-256	SK	1	5	9	25	26	30	34	50
(14 rounds)	RTK	0	0	1	3	5	5	5	10

Comparison of security claims

Deoxys-TBC-256 provides a better resistance than AES-256 against plain related-key attacks, while being more efficient (no Sbox in key-schedule, just byte permutation and a few LFSRs)

Comparing Deoxys-TBC and AES

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Cipher	Model	Rounds							
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AES-256	SK	1	5	9	25	26	30	34	50
(14 rounds)	RTK	0	0	1	3	5	5	5	10

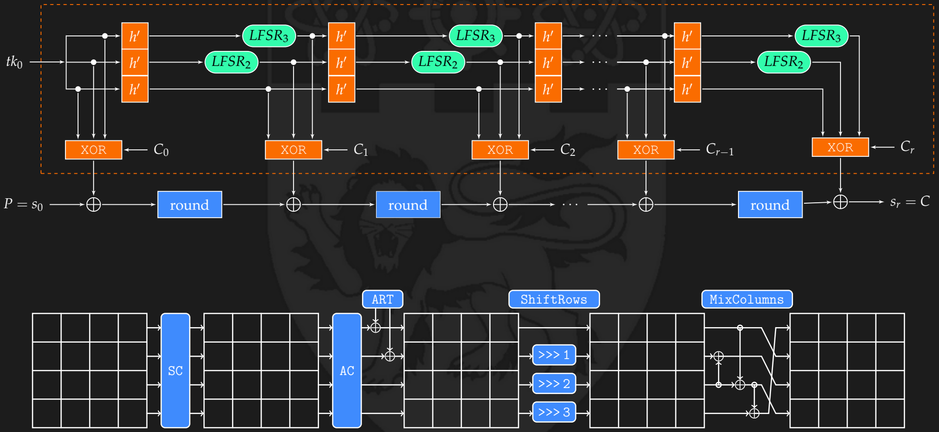
Interesting research topic :

▷ is it be possible to find a permutation that guarantees even more active Sboxes ? Or maybe a different tweakey schedule ?

▷ can an attacker exploit the freedom degrees for more advanced attacks

SKINNY

SKINNY applies this STK idea to lightweight crypto [BJK+-C16]



Ad-hoc TBCs zoo

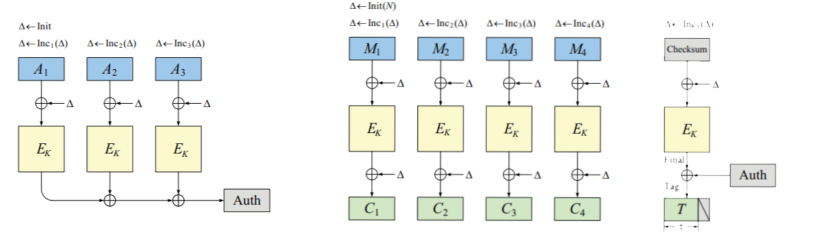
Many other ad-hoc TBCs

Threefish [FLS+-08]
KIASU-TBC, Deoxys-TBC and Joltik-TBC [JNP-AC14]
Minalpher [STA+-14]
Scream and iScream [GLS+-14]
Skinny and Mantis [BJK+-C16]
QARMA [Ava-FSE17]
Clyde-128 [BBB+-19]
Lilliput [ABC+-19]
CRAFT [BLM+-FSE19]
T-Twine [SMS+-I19]
Pholkos [BLLS+-eP20]
...

Outline

Beyond birthday-bound security

Classical BC-based AE modes
only provide birthday security



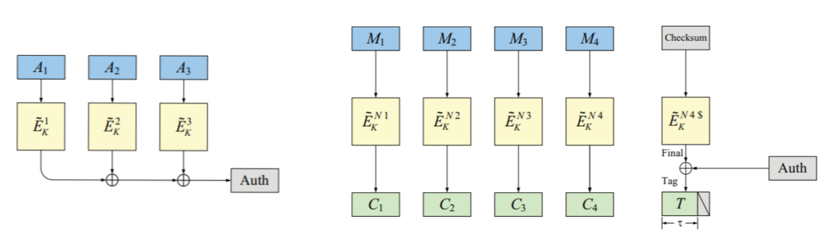
(picture from [KR-FSE11])

Reason : internal collisions on a n-bit value gets you a $q^2/2^n$ term in your security proofs. May lead to birthday complexity attacks. Complex proof.

Ex : OCB3 [KR-FSE11]

Beyond birthday-bound security

TBC-based AE modes can easily provide beyond birthday-bound (BBB) security



(picture from [KR-FSE11])

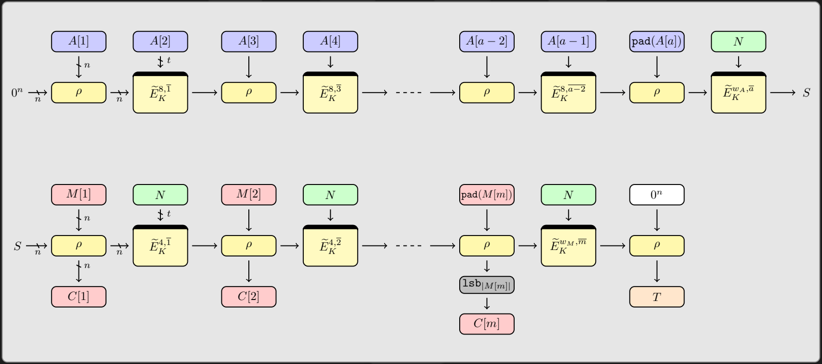
Use tweak input with nonce and counter to always ensure a new TBC instance is called. Easier to understand, better bounds, simpler proofs. priv. bound is 0.

Ex : ΘCB3 [KR-FSE11]

Romulus-N : a lightweight AE mode

Romulus-N [IKMP-19] :
lightweight BBB nonce-respecting AEAD

trades parallelism for small area



(Lightweight) AE modes

Designing an AE mode :

what internal primitive to use?

BC?

Permutation?

TBC?

(Lightweight) AE modes

Designing an AE mode :

what internal primitive to use ?

First we need to get an estimation
of what is the rate of a BC/TBC/Permutation

Permutation ?

TBC ?

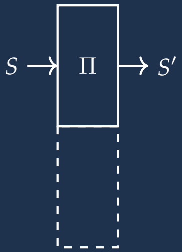
Cost of scaling increasing internal primitives size

We define **rate** according to output size only

Is it justified ?

On scaling costs

Q : assume a n-bit permutation costs x **bitwise operations**, how many do we need to build a $2n$-bit permutation ?



A : at least $\times 2$ and probably a bit more :

- `Keccak` : about $\times 2.2 \sim 2.32$
- `PHOTON` : about $\times 2$
- `SPONGENT` : about $\times 4$

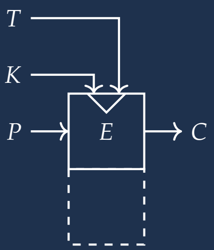
Cost of scaling increasing internal primitives size

We define **rate** according to output size only

Is it justified ?

On scaling costs

Q : assume a n-bit TBC with t-bit tweakey costs x **bitwise operations**, how many do we need to build a $2n$-bit TBC with t-bit tweakey ?



A : at least $\times 2$ and probably a bit more :

- SKINNY : about $\times 2.22$
- GIFT : about $\times 2.84$
- SIMON and SPECK : about $\times 3.16$ and $\times 2.37$

Cost of scaling increasing internal primitives size

We define **rate** according to output size only

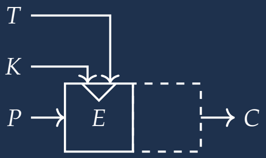
Is it justified ?

On scaling costs

Q : assume a n-bit TBC with t-bit tweakey costs x **bitwise operations**, how many do we need to build a n-bit TBC with $2t$-bit tweakey ?

A : much less than $\times 2$:

- SKINNY : about $\times 1.1 \sim 1.2$
- Deoxys : about $\times 1.3$
- AES (key) : about $\times 1.4$
- SIMON and SPECK (key) : about $\times 1.06$



Cost of scaling increasing internal primitives size

Conclusion :

- increasing block/permutation size costs a lot !
- increasing tweakey size doesn't cost much
- rate should be defined according to the output size

Try to use an internal primitive with the smallest output size as possible for a given security level !

Use case 1 : minimal area

Use case 1 : minimal area

In this scenario, we don't care if the ciphering process is really slow, we just want to minimize area
(typically bit-serial or word-serial implementation)

- We will cipher m-bit at a time (m is small)
- We want at least n-bit security, with a n-bit key

Use case 2 : low energy consumption and lightweight

Use case 2 : low energy consumption and lightweight

In this scenario, we want a small area and good throughput performances (typically round-based implementation)
Efficiency = state size/rate (the lowest the better, basically estimates the inverse of throughput-to-area ratio)

- We will cipher about n-bit at a time
- We want at least n-bit security, with a n-bit key

Use case 3 : fast MAC/encryption

Use case 3 : fast MAC/encryption

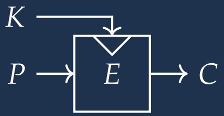
In this scenario, we want good throughput performances (high rate)

- We can cipher more than n-bit at a time, if needed
- We want at least n-bit security, with a n-bit key

Case of block ciphers

Case of BC :

- Most BC modes provide only birthday security (BBB BC-based modes are not lightweight nor fast)
- At least $2n$-bit block cipher with n bit key needed for n-bit security. At very minimal you will need $3n$ (probably impossible ?)
- BC can handle n-bit with a n-bit block, rate is 1



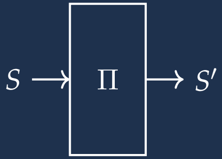
The smallest known, COFB [CIMN-CHES17], actually requires $3n + k = 4n$ state for n-bit security :

- Use case 1 : minimum state is $4n$ (is $< 4n$ possible ?)
- Use case 2 : best efficiency is $state/rate = 4n$
- Use case 3 : best rate is 1

Case of sponges

Case of sponges (DUPLEX) :

- at least a capacity of $2n$ (minimum state size) for n-bit security
- to handle r-bit at a time, $(2n + r)$-bit state is needed for encryption (r-bit for MAC, using full-state DUPLEX)
- rate is $r/(2n + r)$ for encryption, 1 for authentication (full-state DUPLEX)



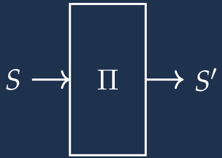
DUPLEX [BDPA-SAC11] would lead to :

- Use case 1 : minimum state is $\longrightarrow 2n$ (for rate $\longrightarrow 0$)
- Use case 2 : best enc. efficiency is $state/rate = 8n$ (at $r = 2n$)
  best auth. efficiency is $state/rate = 2n$ (full-state)
- Use case 3 : best enc. rate is $\longrightarrow 1$ (for rate, state $\longrightarrow \infty$)
  best auth. rate is 1

Case of sponges

Case of sponges (`Beetle`) :

- at least a state of $2n$ (minimum state size) for n-bit security
- to handle r-bit at a time, $(n+r)$-bit state is needed for encryption and authentication
- rate is $1/2$ for encryption and authentication



`Beetle` [CDNY-CHES18] would lead to :

- Use case 1 : minimum state is $2n$
- Use case 2 : best enc./auth. efficiency is $state/rate = 4n$ (at $r = n$)
- Use case 3 : best enc./auth. rate is $\longrightarrow 1$ (for rate, state $\longrightarrow \infty$)

Case of sponges

Case of sponges (`Beetle`) :

- at least a state of $2n$ (minimum state size) for n-bit security
- to handle r-bit at a time, $(n+r)$-bit state is needed for encryption and authentication

full-state `DUPLEX` for authentication + `Beetle` for encryption would have been a great LWC candidate: best of both sponge worlds !

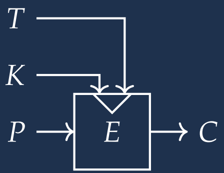
`Beetle` [CDNY-CHES18] would lead to :

- Use case 1 : minimum state is $2n$
- Use case 2 : best enc./auth. efficiency is $state/rate = 4n$ (at $r = n$)
- Use case 3 : best enc./auth. rate is $\longrightarrow 1$ (for rate, state $\longrightarrow \infty$)

Case of tweakable block ciphers

The case of TBC :

- at least a block size of n and a tweakey state of n (to hold the key) for n-bit security
- can handle n-bit at a time for encryption, $(n+t)$-bit for authentication
- rate remains 1 for encryption, $1 + t/n$ for authentication



Romulus-N3 [IKMP-19] requires $3n$ state for n-bit security.

- Use case 1 : minimum state is $3n$
- Use case 2 : best enc. efficiency is $state/rate = 3n$
  best auth. efficiency is $state/rate = n$ (for $t \longrightarrow \infty$)
- Use case 3 : best enc. rate is 1
  best auth. rate is ∞ (for $t \longrightarrow \infty$)

	Min State Size (S)	Max Rate (R)		Best efficiency (S/R)	
		enc.	auth.	enc.	auth.
BC	$4n$ ($\longrightarrow 3n$)	1	1	$4n$	$4n$
Sponge	$2n$	$1/2$ ($\longrightarrow 1$)	1	$4n$	$2n$
TBC	$3n$ ($\longrightarrow 2n$)	1	$1 + t/n$	$3n$	$n < \cdot \leq 1.75n$

Use cases

- **Use case 1 : min. state** with sponges (TBC can also do $2n$)
- **Use case 2 :** best **efficiency** with TBC (reached at lightest point)
- **Use case 3 :** best **rate** with TBC (for auth.)

Comments

- **efficiency of sponge is worse than TBC** in theory because one needs a permutation larger than n (effect reduced with a non-hermetic sponge)
- **TBC :** it seems we can increase the auth rate indefinitely by using a bigger tweak (true in practice ... but only up to a certain level)

128-bit security

Scheme	State Size (S)	Rate (R) enc.	Rate (R) auth.	Efficiency (S/R) enc.	Efficiency (S/R) auth.
Romulus-N1	$3.5n$	1	2	$3.5n$	$1.75n$
Romulus-N3	$3n$	1	7/4	$3n$	$1.71n$
ΘCB3	$4.5n$	1	1	$4.5n$	$4.5n$
COFB	$4n$	1	1	$4n$	$4n$
DUPLEX $(r \ll n)$	$\longrightarrow 2n$	$\longrightarrow 0$	1	$\longrightarrow \infty$	$\longrightarrow 2n$
DUPLEX $(r = n)$	$3n$	1/3	1	$9n$	$3n$
DUPLEX $(r = 2n)$	$4n$	1/2	1	$8n$	$4n$
DUPLEX $(r \gg 2n)$	$\longrightarrow \infty$	$\longrightarrow 1$	1	$\longrightarrow \infty$	$\longrightarrow \infty$
BEETLE	$2.1n$	1/2	1/2	$4.2n$	$4.2n$
ASCON-128	$3.5n$	1/5	1/5	$17.5n$	$17.5n$
Ascon-128a	$3.5n$	2/5	2/5	$8.75n$	$8.75n$

TBC for AE!

Flexibility of the TBC

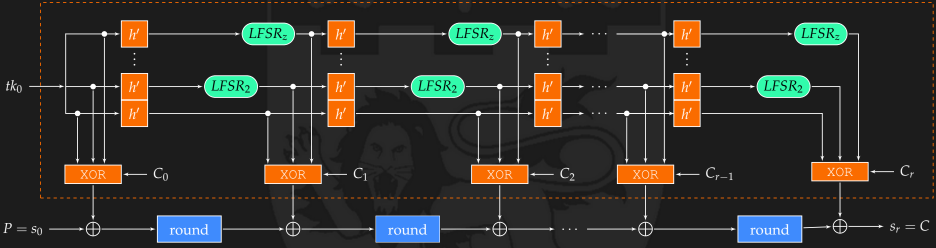
AE mode design process :
fix the **output size** of the TBC according to your security need, then play with the tweak size to get the proper rate and state size according to your constraints.

Don't use a large output size internal primitive if you only want a security of n bits!

Infinitweak

Idea :

Since auth. rate increases with the size of tweak, why not trying constructions with huge tweaks for crazy auth. efficiency ?



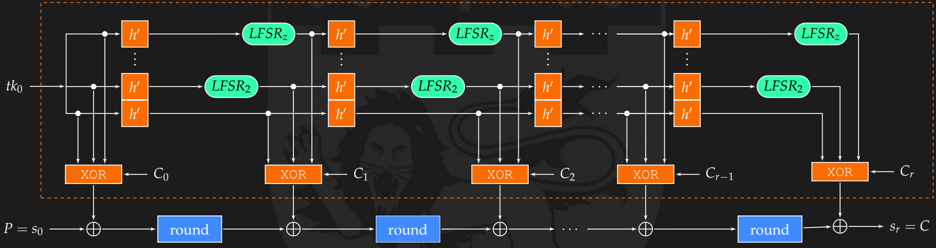
▷ rate will eventually reach a limit, but where ?

▷ Deoxys-128/1024 or Skinny-128/1024 variants would theoretically provide 50% ∼ 100% speed-up (ongoing work)

Infinitweak

Idea :

Since auth. rate increases with the size of tweak, why not trying constructions with huge tweaks for crazy auth. efficiency ?



Interesting research topic :

- ▷ How can we design such a very large tweak TBC ?
- ▷ What tweakey construction to minimize cancellations ?

Outline

Side-channels resistance

Side-channels resistance

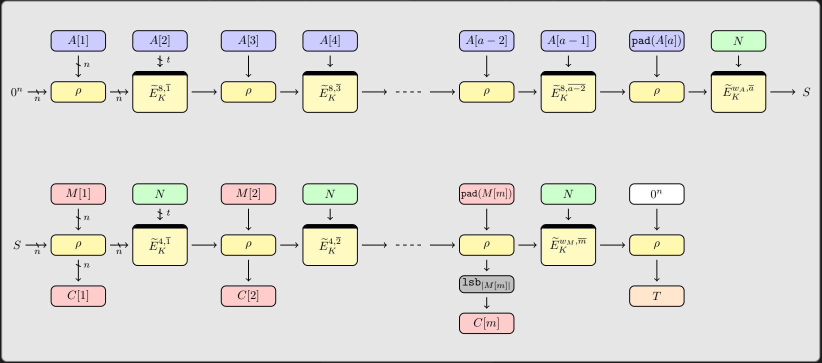
Side-channels have become a crucial threat to take into account during design phase :

- leakage-resilient AE modes
- protected implementations : masking, threshold implementations, etc.

What advantage can TBCs offer here ?

AET-LR : leakage resilient AE from TBC

One can get some leakage resilience by simply feed-forwarding blocks into the tweak input in Romulus-N + key/tag protect



AET-LR : leakage resilient AE from TBC

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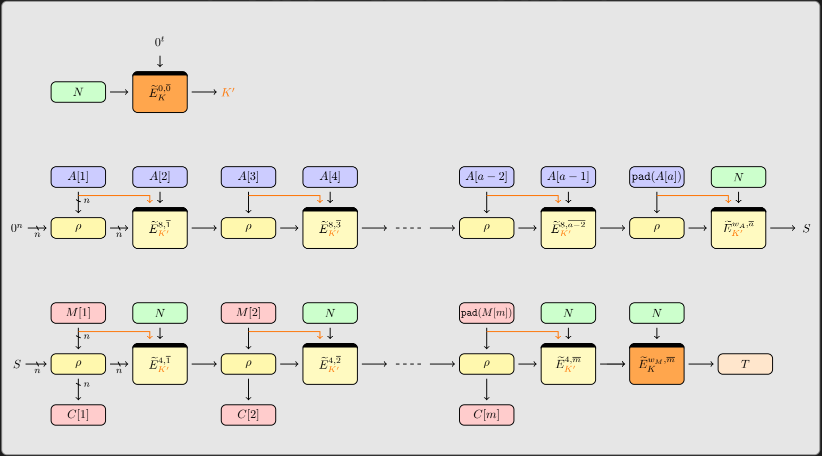
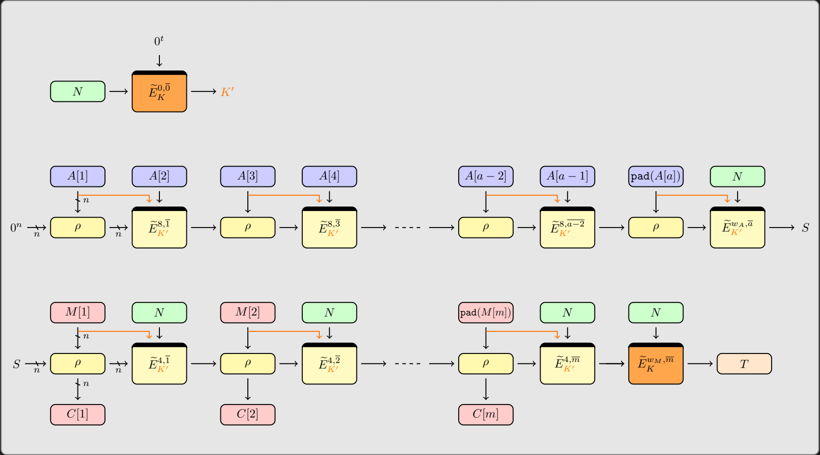


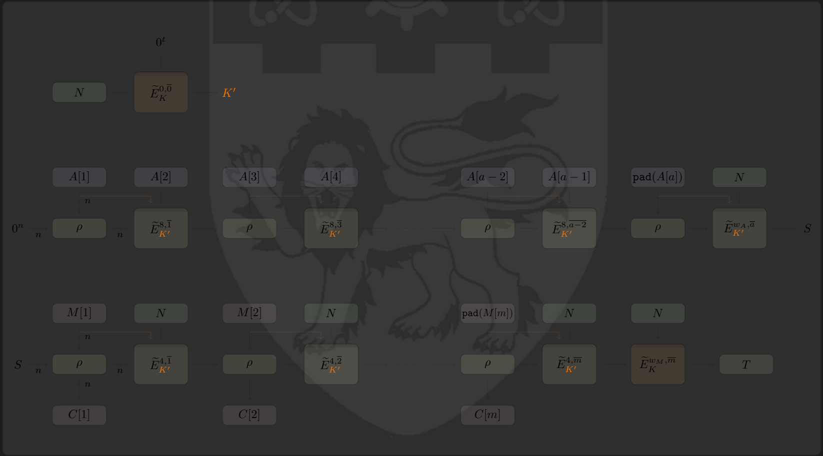
AET-LR : leakage resilient AE from TBC

AET-LR [GKP-LWC20] (used in Romulus-LR) ensures
CIML2 (best for integrity) + CCAml1



TEDT : stronger leakage resilient AE from TBC

TEDT [BGP+-CHES20] (used in Romulus-LR-TEDT) ensures CIML2 (best for integrity) + CCAmL2 (best for privacy)



Threshold implementations

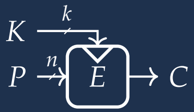
For threshold implementations (TI) :

- Threshold Implementations (TI) area increases with the number of shares
- for a masking order d and algebraic degree t of the target function, the number of shares is $dt + 1$
- thus $t + 1$ for first-order TI, count :
  - 3 shares per internal state bit,
  - 2 shares per key bit (if linear key schedule),
  - no protection for tweak material

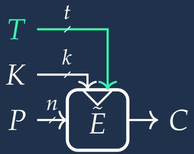
[NS-CHES20] and [NSS-EC20] remarked that TBCs present a fundamental advantage :
only a reduced part of the state needs to be protected

Threshold implementations comparison (for n-bit security)

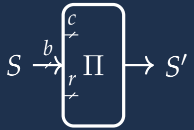
BC-based schemes : at least $2n$ state (because up-to-birthday secure) and n bit key to be protected.
Total state : $3 \cdot (2n) + 2 \cdot (n) = 8n$.



TBC-based schemes : possible with n bit state and n-bit key to be protected (and n-bit unprotected tweak).
Total state : $3 \cdot (n) + 2 \cdot (n) + n = 6n$.

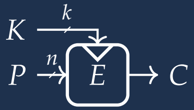


permutation-based schemes : need to protect the entire state ($2n + r$ bit for duplex, $2n + \log s$ bit for Beetle). **Total state :**
Duplex : $3 \cdot (2n + r) = 6n + 3r$
Beetle : $3 \cdot (2n + \log n) = 6n + 3 \log n$.

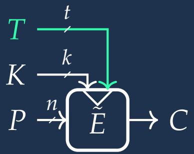


Threshold implementations comparison (for n-bit security)

BC-based schemes : at least $2n$ state (because up-to-birthday secure) and n bit key to be protected.
Total state : $3 \cdot (2n) +$ ~~2·~~ $(n) = 7n$.



TBC-based schemes : possible with n bit state and n-bit key to be protected (and n-bit unprotected tweak).
Total state : $3 \cdot (n) +$ ~~2·~~ $(n) + n = 5n$.



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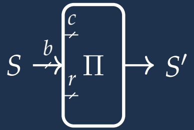


Outline

1. Introduction
2. Tweakable Block Ciphers Designs
   - Block Cipher-Based TBC
   - Ad-hoc TBC Constructions
3. Tweakable Block Ciphers for AE
4. TBC for Side-Channels Protection
   - Leakage Resilience and Protected Implementations
5. Conclusion

Future Works

TBCs are promising primitives

- many more applications :
  - Forkcipher for small messages [ALP+-AC19]
  - easy misuse-resistance/RUP, for example with Romulus-M [IKMP-19]
  - Multi-users security (ongoing work with B. Cogliati) : put separately counter, nonce and key in the tweak input of the TBC !
  - Hashing/XOF for example with Naito's MDPH [N-LC19] construction used for Romulus-H. Ongoing work : **blazing fast** Deoxys-TBC**-based hash function** with speed similar to `KangarooTwelve` [BDP+-ACNS18]
  - backdoor ciphers (MALICIOUS framework [PW-C20]) can use TBC with XOF-based tweak schedule
  - etc.
- many open problems, many interesting research topics for TBCs, both in cryptanalysis and design

We're hiring!

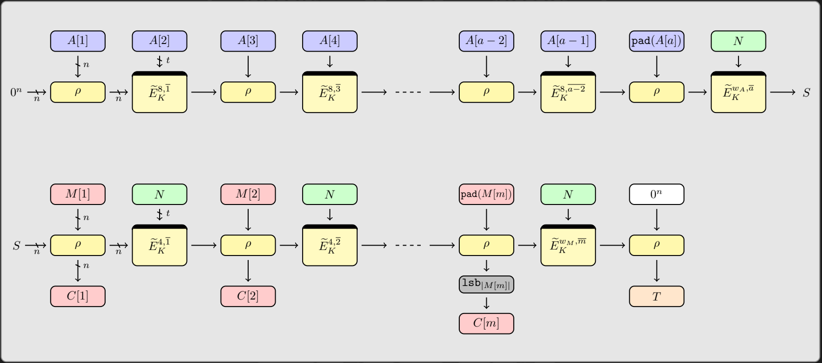
Looking for a PhD/postdoc position to work on anything related to cryptography?

Contact me!

Thank you!

Romulus-N : a lightweight BBB nonce-respecting AEAD

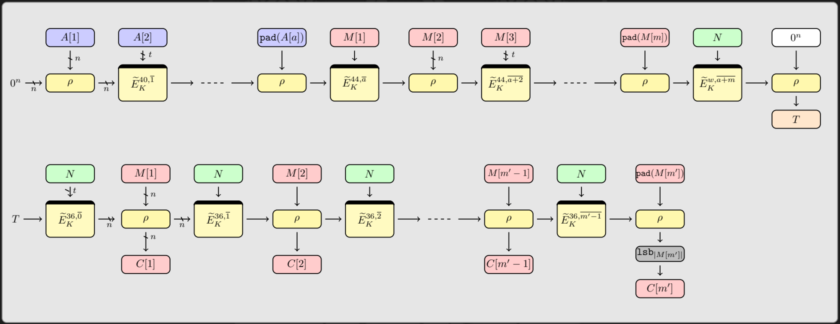
Romulus-N [IKMP-19] : lightweight BBB nonce-respecting AEAD



- provably secure in standard model
- full 128-bit security
- low overhead for small messages : 1 AD + 1 M = 2 TBC calls
- priv. bound is 0, auth is $q_d/2^\tau$, doesn't depend on #enc queries

Romulus-M : a lightweight BBB nonce-misuse AEAD

Romulus-M [IKMP-19] : lightweight BBB nonce-misuse resistant AEAD



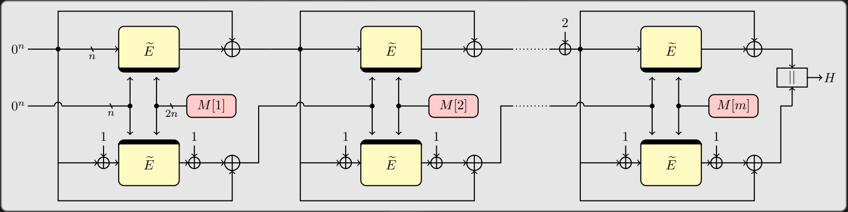
- provably secure in standard model
- full 128-bit security in nonce-respecting, birthday with graceful degradation so ~full security in nonce-misuse
- easy nonce-misuse resistance mode
- RUP secure [ABL+-AC14] (INT-RUP and PA1)

Romulus-H : 256-bit hashing with a 128-bit TBC

Easy to hash using a 128-bit TBC with Naito's MDPH [N-LC19] :

- build a 256-bit compression function h with the well-known **Hirose DBL** construction (rate 1) [H-FSE06]
- place h into the **Merkle-Damgård with Permutation** (MDP) mode [HPY-AC07]

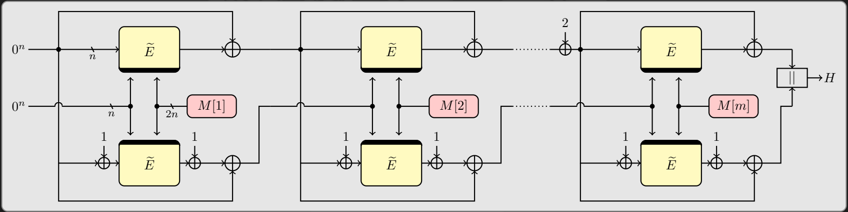
MDPH is indifferentiable from a (variable-input-length) random oracle up to about $(n - \log n)$ queries



Romulus-H : 256-bit hashing with a 128-bit TBC

Extra features of Romulus-H [IKMP-LWC20] :

- XOF : simply use $H(M||0), H(M||1), H(M||2)$, etc.
- Romulus-H can naturally adapt to very constrained area environments by reducing its message block size



Interesting research topic : hashing with TBC

Interesting research topic :

▷ can we build a blazing fast hash function using larger tweak inputs ? First back-of-the-envelope estimations show that a Deoxys-TBC based hash would already lead to software speeds similar to `KangarooTwelve` [BDP+-ACNS18]

▷ can we leverage TBC capabilities to build efficient and simple parallel hashes ?