Deoxys

A Proposal for Beyond-Birthday Nonce-Misuse Authenticated Encryption

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Outline

1. The Deoxys-BC TBC
2. The SCT Authenticated Encryption Mode
3. The ZMAC MAC and ZAE AEAD modes

What is a authenticated encryption ?

Authenticated Encryption = Authentication + Encryption

Goal of authenticated encryption :

- avoid numerous issues that can arise when using separate authentication and encryption primitives (`https://competitions.cr.yp.to/disasters.html`)
- efficiency gain
- add feature of having authenticated-only data : Authenticated Encryption with Associated Data (AEAD)

Hot topic :

5-year CAESAR competition (2014-2019) :
Competition for Authenticated Encryption : Security, Applicability, and Robustness

What is beyond-birthday security ?

Problem : Most cipher modes have security bounds in $q^2/2^{128}$ for a 128-bit cipher (birthday bounds), q is number of queries.

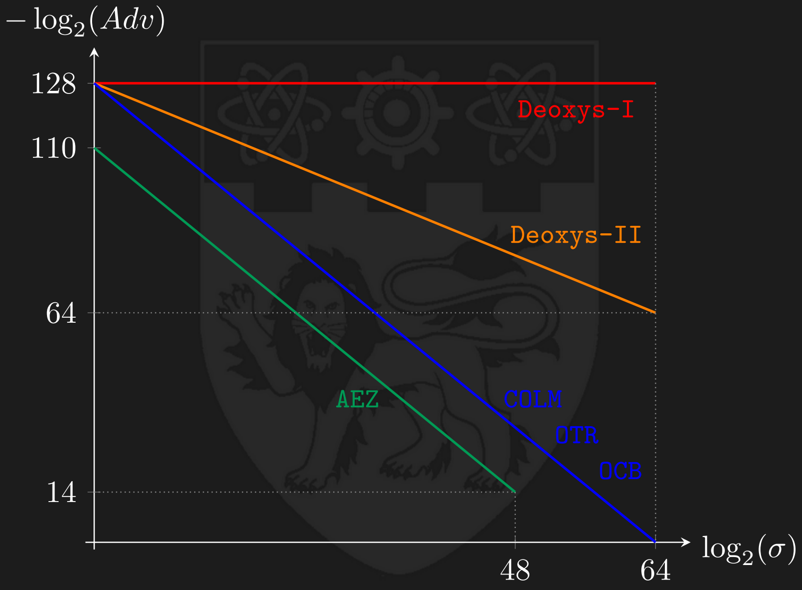
This means that after about 2^{64} data all security is lost.

Examples : `OCB`, `AES-GCM`, etc. provide only birthday bounds.

Solution : Beyond birthday modes provide beyond $2^{n/2}$ security, potentially up to full 2^n.

This effectively avoids strong data constraints issues.

Security claims - a comparison of the nonce-respecting case



What is nonce-misuse resistance ?

Problem : Most cipher modes will have their security completely removed if the nonce is repeated just a single time.

This creates a lot of problems :

- if the nonce is generated randomly :
  need to make sure of proper randomness source
- if the nonce is a counter :
  need to constantly maintain a state
- other mechanisms required to make sure no repetition

Examples : `OCB`, `AES-GCM`, etc. are completely broken if the nonce is repeated just once (universal forgery and decryption)

Solution : Nonce-misuse resistant modes will maintain security even if the nonce is repeated, a really robust defence in depth feature.

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2. The SCT Authenticated Encryption Mode
3. The `ZMAC` MAC and `ZAE` AEAD modes

Deoxys-BC

- DEOXYS-BC -

J. Jean, I. Nikolic, T. Peyrin

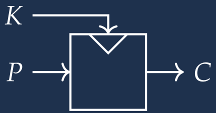
ASIACRYPT 2014

WINNER OF THE CAESAR COMPETITION
(Defense in depth portfolio)

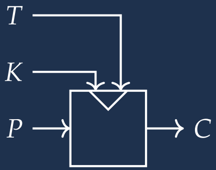
Paper, Specifications, Results and Updates available at :
https://sites.google.com/view/deoxyscipher/

What is a (tweakable) block cipher ?

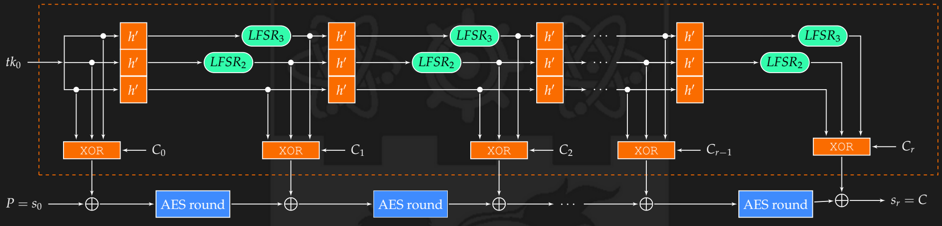
Block cipher (BC) : a family of permutations parametrized by a secret key K. **Example :** `AES`



Tweakable block cipher (TBC) : a family of permutations parametrized by a secret key K and a tweak value T [LRW02]. **Example :** `Deoxys-BC`



The Deoxys-BC tweakable block ciphers



- The round function is **exactly** the AES round function
- h' is a simple permutation of the bytes positions
- The LFSRs can be clocked with a single XOR
- Constant additions to break symmetries (RCON from AES KS)

Deoxys-BC security and efficiency

2 versions : Deoxys-BC-256 and Deoxys-BC-384

128-bit tweakable block ciphers

- Deoxys-BC-256 : **14 rounds** and 256-bit tweakey
- Deoxys-BC-384 : **16 rounds** and 384-bit tweakey

- Security guarantees for differential/linear cryptanalysis (both single and related-key)
- A lot of 3rd party cryptanalysis since 2014, still comfortable security margin
- Reuses analysis already performed on AES
- Accepts 256-bit keys (post-quantum security)
- Very efficient software implementations (mostly AES round function), on Skylake (avx2) for fixed key :
  - 0.87 c/B for Deoxys-BC-256
  - 0.99 c/B for Deoxys-BC-384
- no patent

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Deoxys-BC

- SCT AEAD mode -

T. Peyrin, Y. Seurin
CRYPTO 2016

WINNER OF THE CAESAR COMPETITION
(Defense in depth portfolio)

Deoxys-II **=** Deoxys-BC **+** SCT

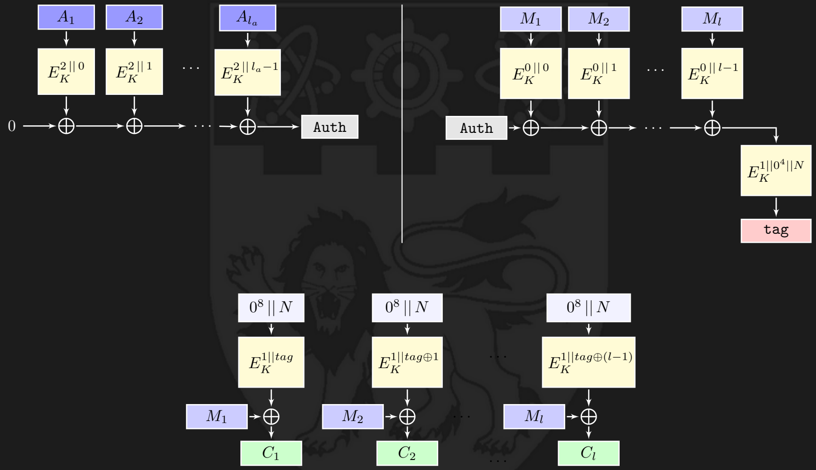
Paper, Specifications, Results and Updates available at :
https://sites.google.com/view/deoxyscipher/

The SCT authenticated encryption mode

SCT is :

- a simple TBC-based AEAD mode
- 2 pass mode (because of nonce-misuse resistance)
- with full n-bit security in nonce-respecting scenario
- with $n/2$-bit security in nonce-misuse scenario (but linear degradation of security with the maximal number of nonce repetition, so in practice $\sim$ n-bit security).
  Strong MRAE security notion.
- when instantiated with Deoxys−BC, it is very efficient
- no precomputation, almost no overhead for small messages
- fully parallel, inverse-free
- extra tweak input for other purposes (leakage resilience)
- provably secure (security proofs in the article)
- no patent

The SCT AEAD mode



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Deoxys-BC

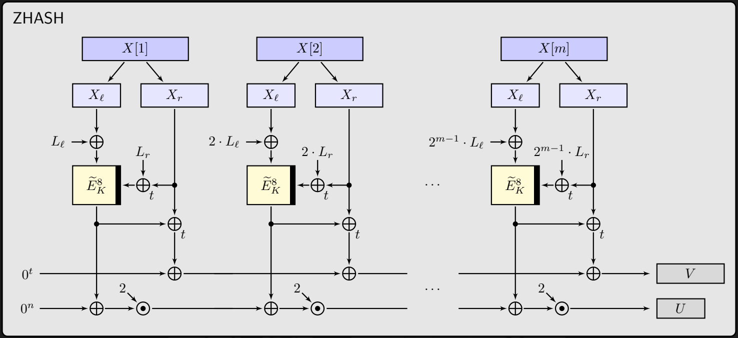
- ZMAC/ZAE -

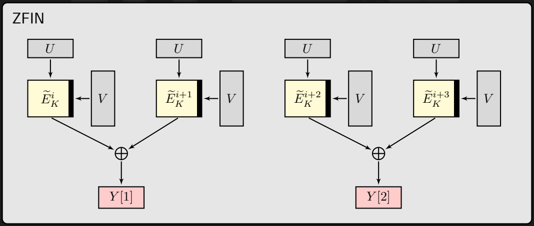
T. Iwata, K. Minematsu, T. Peyrin and Y. Seurin

CRYPTO 2017

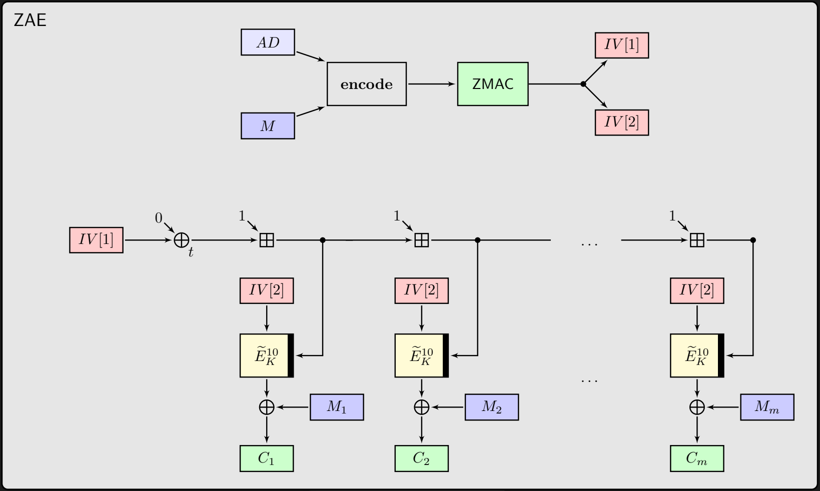
Paper and Specifications available at :
https://eprint.iacr.org/2017/535.pdf

The ZMAC MAC mode





The ZAE AEAD mode



The ZMAC MAC mode and ZAE AEAD mode

ZMAC and ZAE are :

- a TBC-based MAC mode and a TBC-based AEAD mode
- with full n-bit security for both the nonce-respecting and nonce-misuse scenario (strong MRAE sense)
- **can handle $n + t$ bits of message per TBC call (optimal)**
- when instantiated with Deoxys-BC, it is faster than PMAC-AES, with a much higher security !
- fully parallel, inverse-free
- extra tweak input for other purposes (leakage resilience)
- provably secure (security proofs in the article)
- no patent

Comparison

AES-GCM-SIV - Deoxys-II - ZAE

Comparison of Deoxys-II and ZAE with AES-GCM-SIV

- **winner of the CAESAR competition**, well scrutinized
- **much** simpler and flexible than AES-GCM-SIV
- GCM family very sensitive to timing attacks, while trivial and efficient constant time impl. for Deoxys-II and ZAE
- **higher security** : for 2^{32} messages of 64 KB each, attacker advantage for authenticity is
  - 2^{-37} for OCB (1 in nonce-misuse)
  - 2^{-73} for AES-GCM-SIV (2^{-41} in nonce-misuse)
  - 2^{-94} for Deoxys-II (2^{-51} in nonce-misuse)
  - 2^{-144} for ZAE (2^{-144} in nonce-misuse)
- more efficient in hardware, inverse-free
- can easily offer the Deoxys-I mode (twice faster, full 128-bit security for nonce-respecting)
- tweak input can be used for many other things : disk encryption, leakage resilience, hashing, sessions, etc.

Comparison of Deoxys-II and ZAE with AES-GCM-SIV

Software efficiency estimations (in AES rounds) :

1 GF(2^{128}) mult. $\simeq$ 6 AES rounds - actually more on ARM

1 AES Key schedule $\simeq$ 10 AES rounds

	M block	A block	init/tag
AES-GCM-SIV	16	6	66
Deoxys-II	28	14	14
ZAE	21	7	56

Internet Mix efficiency estimations (in AES rounds) :

7 packets of 40B, 4 packets of 576B, 1 packet of 1500B

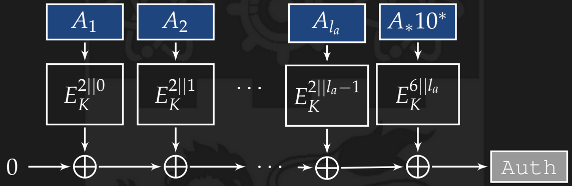
	40 Bytes	576 Bytes	1500 Bytes
AES-GCM-SIV	114	642	1570
Deoxys-II	98	1022	2646
ZAE	119	812	2030

Thank you !

Nonce-respecting AEAD : Deoxys-I

Deoxys-I is similar to TAE or OCB

For associated data authentication :



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