Adiantum: length-preserving encryption for entry-level processors

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Overview

- The problem
- The solution

Section 1

The problem

The problem

- Hardware (eg ARM CE) makes AES fast
- ...but some devices don't have it

The solution (for TLS)

- RFC7539
  - ChaCha for encryption
  - Poly1305 for authentication
- Much faster

But...

- RFC7539 is an AEAD mode, so $|C| > |P|$
  - nonce
  - MAC
- Storage encryption requires $|C| = |P|$

Full disk encryption

- 4KiB virtual sector <-> 4KiB real sector
- No special flash hardware

File based encryption

- Databases update sectors
- If read/write of one sector touches two sectors...
  - Atomicity more difficult
  - Speed is halved
  - Lifetime is halved

Android

Android “Compatibility Definition Document”, version 8.1, section 9.9:

> *If device implementations [...] support data storage encryption with Advanced Encryption Standard (AES) crypto performance above 50MiB/sec, they MUST enable the data storage encryption by default [...]*

Section 2

The solution

Formal properties

- Deterministic
- No nonce
- Tweakable super-pseudorandom permutation (SPRP)
  - family of permutations indexed by tweak and length
  - indistinguishable from random permutations
  - attacker can query f, f^{-1}

AES-XTS

- 128-bit tweakable SPRP
- 4KiB sector: applied 256 times
- Two-part tweak
- Cortex A7: 58.6 cpb (decryption)

Whole sector encryption

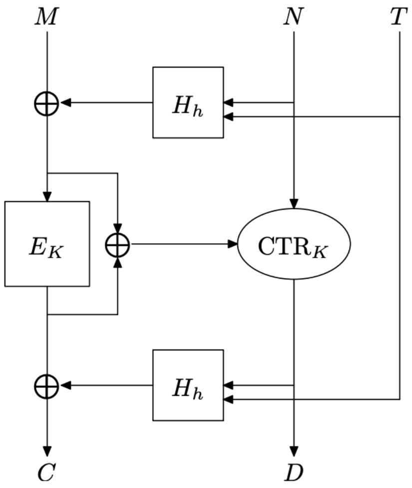
- 4KiB tweakable SPRP
- every bit of plaintext affects all of ciphertext
- every bit of ciphertext affects all of plaintext
- every tweak a new permutation
- opportunity to be faster

Three-pass structure

- SPRP: read all before writing any
- same in decryption direction
- minimum three passes
- hash-XOR-hash faster than XOR-hash-XOR

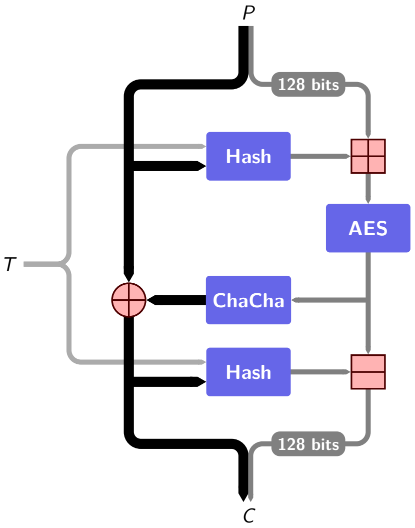
HCTR, HCH

- hash-XOR-hash structure
- Block cipher defeats LR attack
- But no faster on our hardware (AES, $GF(2^{128})$)



HPolyC and Adiantum

- Similar structure: hash-XOR-hash with block cipher
- More parallel decryption
- Use RFC7539 primitives
- HPolyC-ChaCha20-AES: 17.8 cpb
- Use ChaCha12 instead: HPolyC, 13.6 cpb
- Use NH
- ...but combine with Poly1305
- Adiantum: 10.6 cpb



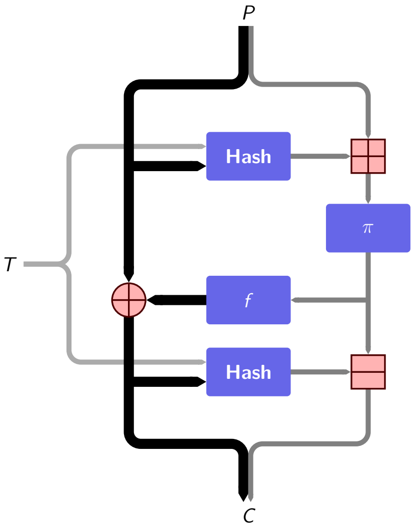
Performance

Table: Performance on ARM Cortex-A7

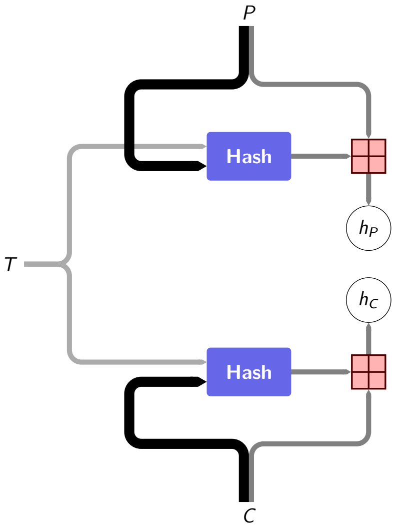
Algorithm	cbp (4096)	cpb (512)
Adiantum-XChaCha12-AES	**10.6**	**15.8**
HPolyC-XChaCha12-AES	**13.6**	**18.7**
Adiantum-XChaCha20-AES	14.7	20.2
Speck128/256-XTS	15.8	16.9
HPolyC-XChaCha20-AES	17.8	23.4
NOEKEON-XTS	26.9	27.9
AES-128-XTS (decryption)	42.7	43.9
AES-256-XTS (decryption)	58.6	60.1

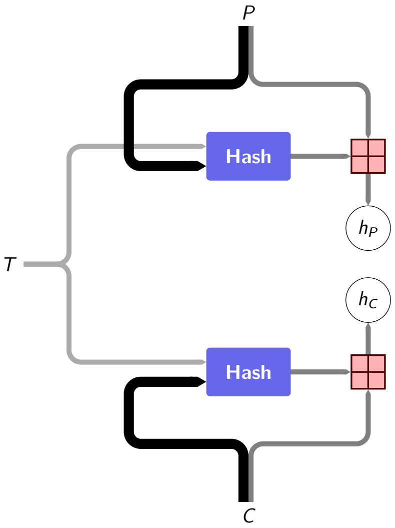
Proof (main step)

- Adversary distinguishes world X and world Y
- Plaintext, ciphertext queries, any length and tweak
- World X: Adiantum, with random permutation π and random function f
- World Y: all answers random
- H-coefficient technique
- After final query, attacker gets the hash key



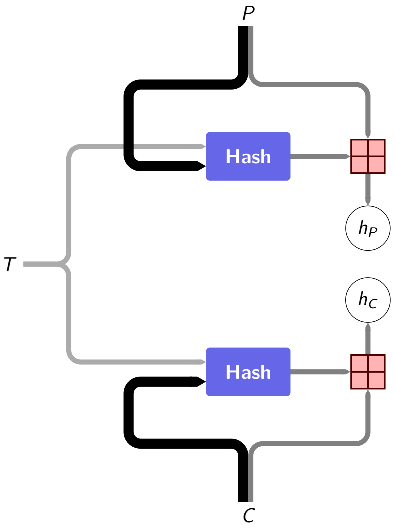
Bad transcripts





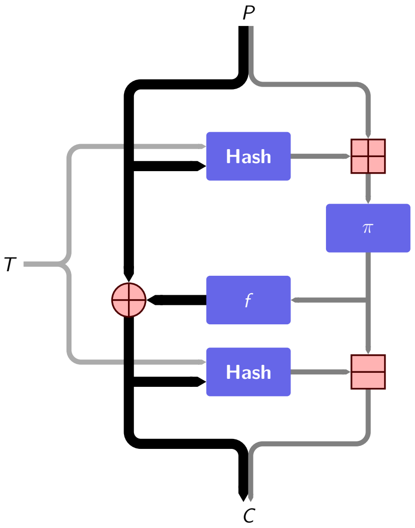
Bad transcripts

- Results are random in world Y
- Collision in result: 2^{-128}
- We forbid pointless queries
- Collision in query: at most ϵ
- Total across all queries: at most $(\epsilon + 2^{-128})\binom{q}{2}$



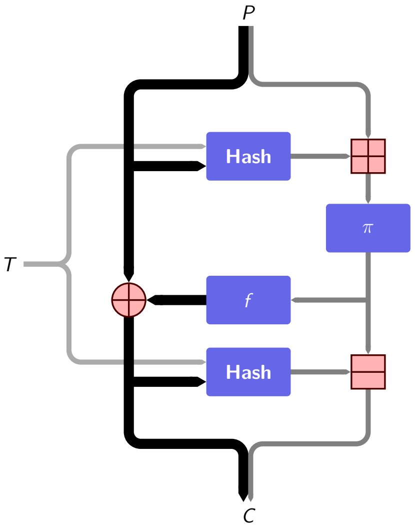
Good transcripts

- In world Y, all responses have probability $2^{-|P|}$
- In world X
  - probability f has right output: $2^{-(|P|-128)}$
  - probability π has right output: $\frac{1}{2^{128}-i}$
  - where i is the number of queries before this one
- These are independent, so overall probability is $2^{-(|P|-128)}\frac{1}{2^{128}-i}$
- ...which is equal to or slightly larger than $2^{-|P|}$



H-coefficient technique

- Every good transcript is at least as likely in world X as world Y
- Probability of bad transcript $\leq (\epsilon + 2^{-128})\binom{q}{2}$
- By H-coefficient technique, distinguishing advantage $\leq (\epsilon + 2^{-128})\binom{q}{2}$



Security

Distinguishing bound quadratic in queries, linear in message/tweak lenth

$$(3(2^{-128}) + 2^{-103} \max(1 + \lceil l_T/128 \rceil, 2 \lceil (l_M - 128)/8192 \rceil)) \binom{q}{2}$$
$$+\mathrm{Adv}^{\mathrm{sc}}_{S_{K_S}}(1 + q, 9088 + q(l_M - 128), t') + \mathrm{Adv}^{\pm\mathrm{prp}}_{E_{K_E}}(q, t')$$

where

- q: number of queries
- l_T, l_M: maximum length of tweak, message in bits
- $\mathrm{Adv}^{\pm\mathrm{prp}}_{E_{K_E}}(q, t')$: distinguishing advantage against AES-256
- $\mathrm{Adv}^{\mathrm{sc}}_{S_{K_S}}(q, l, t')$: distinguishing advantage against XChaCha12
- $t' = t + \mathcal{O}(q(l_T + l_M))$

Adiantum in Android

- Part of Linux 5.0
- Android "dessert" releases
  - Cupcake, Donut, Eclair, ...
  - ..., Oreo (2017), **Pie (2018)**, **"Q" (2019)**
- Some Android Pie devices will use it
- No carveout: devices shipping "Q" will all be encrypted