SoK: Security of the Ascon Modes

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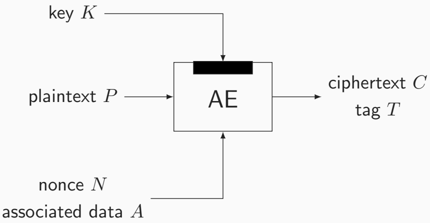
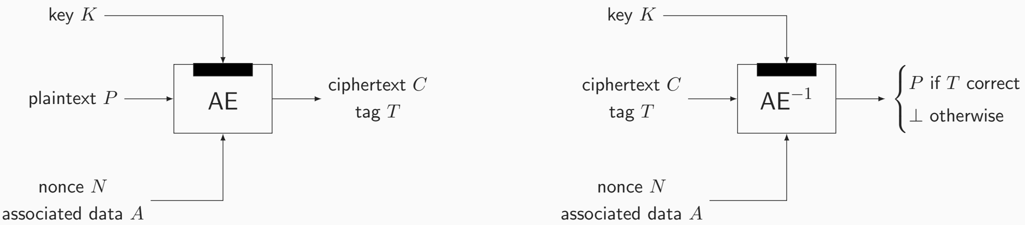
Introduction

Authenticated Encryption



- Using key K:
  - Ciphertext C encrypts plaintext P
  - Tag T authenticates (N, A, P)

Authenticated Encryption



- Using key K:
  - Ciphertext C encrypts plaintext P
  - Tag T authenticates (N, A, P)
- Unwrapping needs to satisfy that
  - Plaintext disclosed if tag is correct
  - Plaintext is not leaked if tag is incorrect

CAESAR Competition

- 2014–2019
- Call for authenticated encryption scheme
- 57 submissions (of which $\approx$ 10 sponge/duplex-based)
- Ascon selected as winner in category lightweight applications

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NIST Lightweight Cryptography Competition

- 2019–2023
- Call for authenticated encryption scheme and, optionally, hash function
- 57 submissions (of which $\approx$ 22 sponge/duplex-based)
- Ascon selected as winner

Ascon [DEMS21]

Ascon [DEMS21]

Authenticated Encryption

- Duplex-based but with additional key blindings

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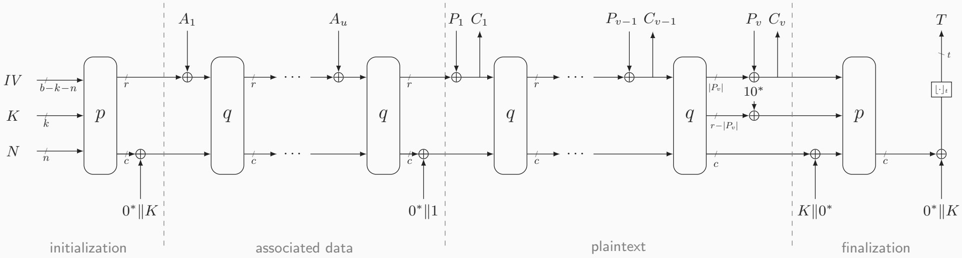
Hashing

- Sponge-based hashing and XOFing
- Only included in NIST Lightweight Cryptography submission

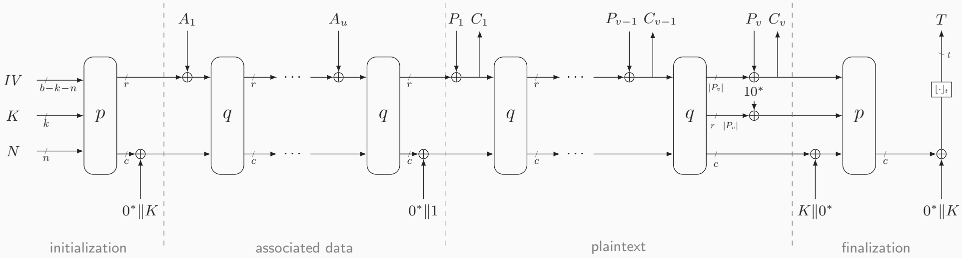
Ascon-AE



Variant of SpongeWrap [BDPV11]

- Outer permutation p and inner permutation q, both on b bits
  - r is the rate, c is the capacity (security parameter)

Ascon-AE



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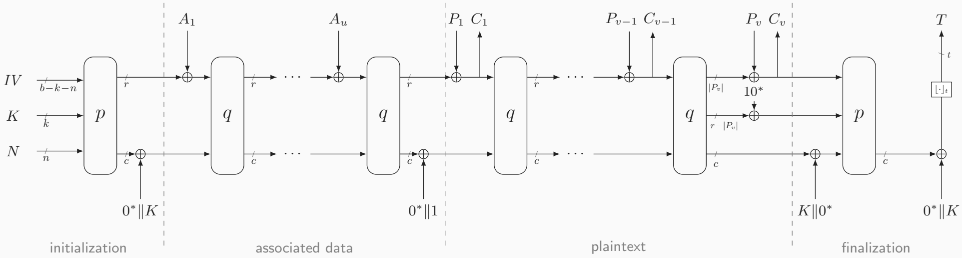

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- Outer permutation p and inner permutation q, both on b bits
  - r is the rate, c is the capacity (security parameter)
- Additional key blindings around "outer" permutations
- Domain separation simplified and spilled-over into inner part

SpongeWrap and Similar

History of Generic Security Results (1/2)

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2011 Bertoni et al. [BDPV11]
Duplex and SpongeWrap

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none of these results deals with additional key blindings

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2025 Lefevre and Mennink (this work)
Let's clean this up!

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- Three flavors of conventional security:
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- We categorize existing lower and upper bounds
- We derive new security bounds and matching attacks where needed
- All results assume that $p = q$ is a random permutation

Overview of Results on Ascon-AE

nonce-respecting security
confidentiality
authenticity

Overview of Results on Ascon-AE

nonce-respecting security	
confidentiality	$\frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$
authenticity	$\frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$

μ	number of users
$Q_E/\mathcal{M}_E$	encryption queries/complexity
$Q_D/\mathcal{M}_D$	decryption queries/complexity
$Q/\mathcal{M}$	construction queries/complexity
$\mathcal{N}$	permutation queries

bounds of [CDN23, CDN24]
carry over
new: matching attacks

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core term $(\star)$

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core term $(\star)$

nonce-misuse resistance	
confidentiality	1
authenticity	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c}$

μ number of users
$Q_E/\mathcal{M}_E$ encryption queries/complexity
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new: flaw in proof of [CDN24]
new: transformation of [LM24] to $p = q$ setting
new: matching attacks

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nonce-misuse resilience	
confidentiality	$(\star) + \frac{\mathcal{M}_E\mathcal{N}}{2^c}$
authenticity	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c}$

nonce-misuse resistance	
confidentiality	1
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analysis of [GPPS19] incomplete
new: security bounds
and matching attacks

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$\Longleftarrow$

nonce-misuse resilience	
confidentiality	$(\star) + \frac{\mathcal{M}_E\mathcal{N}}{2^c}$
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confidentiality	$(\star) + \frac{\mathcal{M}_E\mathcal{N}}{2^c}$
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leakage resilience, no leakage	
confidentiality	
authenticity	

leakage resilience, limited	
confidentiality	
authenticity	

leakage resilience, unlimited	
confidentiality	
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Overview of Results on Ascon-AE

nonce-respecting security	
confidentiality	$\frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{MN}}{2^b} + \frac{\mathcal{N}}{2^c}$
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nonce-misuse resilience	
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nonce-misuse resistance	
confidentiality	1
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$\Updownarrow$

leakage resilience, no leakage	
confidentiality	$(\star) + \frac{\mathcal{M}_E\mathcal{N}}{2^c}$
authenticity	$(\star) + \frac{\mathcal{MN}}{2^c}$

follows by equivalence

leakage resilience, limited	
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nonce-misuse resistance	
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core term $(\star)$

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leakage resilience, limited	
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analysis of [GPPS19] incomplete
and in different model
new: security bounds
and matching attacks

leakage resilience, unlimited	
confidentiality	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c} + \min\left\{\frac{\mathcal{N}^2}{2^c}, \frac{Q\mathcal{N}}{2^k}\right\}$
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core term $(\star)$

nonce-misuse resilience	
confidentiality	$(\star) + \frac{\mathcal{M}_E\mathcal{N}}{2^c}$
authenticity	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c}$

nonce-misuse resistance	
confidentiality	1
authenticity	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c}$

nonce-respecting security $\Longleftarrow$ nonce-misuse resilience $\Longleftarrow$ nonce-misuse resistance

nonce-misuse resilience $\Updownarrow$ leakage resilience, no leakage

leakage resilience, no leakage	
confidentiality	$(\star) + \frac{\mathcal{M}_E\mathcal{N}}{2^c}$
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$\Uparrow$

leakage resilience, limited	
confidentiality	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c} + \min\left\{\frac{\mathcal{N}^2}{2^c}, \frac{Q\mathcal{N}}{2^k}\right\}$
authenticity	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c} + \min\left\{\frac{\mathcal{N}^2}{2^c}, \frac{Q\mathcal{N}}{2^k}\right\}$

$\Uparrow \quad \Downarrow\cap$

leakage resilience, unlimited	
confidentiality	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c} + \min\left\{\frac{\mathcal{N}^2}{2^c}, \frac{Q\mathcal{N}}{2^k}\right\}$
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follows by implication

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$\Longleftarrow$

nonce-misuse resistance	
confidentiality	1
authenticity	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c}$

$\Updownarrow$

leakage resilience, no leakage	
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$\Uparrow$

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$\Uparrow \quad \Downarrow$

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$\Longleftarrow$

state-recovery security	
confidentiality	1
authenticity	$(\star) + \frac{\mathcal{N}^2}{2^c}$

new: transformation of [LM24] to $p = q$ setting

new: matching attacks

Overview of Results on Ascon-AE

nonce-respecting security	
confidentiality	$\frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$
authenticity	$\frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$

$\Longleftarrow$

nonce-misuse resilience	
confidentiality	$(\star) + \frac{\mathcal{M}_E\mathcal{N}}{2^c}$
authenticity	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c}$

$\Longleftarrow$

nonce-misuse resistance	
confidentiality	1
authenticity	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c}$

core term $(\star)$

μ	number of users
$Q_E/\mathcal{M}_E$	encryption queries/complexity
$Q_D/\mathcal{M}_D$	decryption queries/complexity
$Q/\mathcal{M}$	construction queries/complexity
$\mathcal{N}$	permutation queries

$\Updownarrow$

leakage resilience, no leakage	
confidentiality	$(\star) + \frac{\mathcal{M}_E\mathcal{N}}{2^c}$
authenticity	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c}$

$\Uparrow$

leakage resilience, limited	
confidentiality	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c} + \min\left\{\frac{\mathcal{N}^2}{2^c}, \frac{Q\mathcal{N}}{2^k}\right\}$
authenticity	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c} + \min\left\{\frac{\mathcal{N}^2}{2^c}, \frac{Q\mathcal{N}}{2^k}\right\}$

RUP security	
confidentiality	1
authenticity	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c}$

$\Uparrow$ $\Downarrow^{c}$

$\Uparrow^{\text{auth}}$

leakage resilience, unlimited	
confidentiality	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c} + \min\left\{\frac{\mathcal{N}^2}{2^c}, \frac{Q\mathcal{N}}{2^k}\right\}$
authenticity	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c} + \min\left\{\frac{\mathcal{N}^2}{2^c}, \frac{Q\mathcal{N}}{2^k}\right\}$

$\Longleftarrow$

state-recovery security	
confidentiality	1
authenticity	$(\star) + \frac{\mathcal{N}^2}{2^c}$

new: security bounds
and matching attacks

Simplified Numerical Interpretation

setting	confidentiality as long as	authenticity as long as
nonce-respecting		
nonce-misuse resilience		
nonce-misuse resistance		
state-recovery security		

Simplified Numerical Interpretation

setting	confidentiality as long as	authenticity as long as
nonce-respecting	$\mathcal{N} \ll \min\{2^k/\mu, 2^b/\mathcal{M}, 2^c\}$	$\mathcal{N} \ll \min\{2^k/\mu, 2^b/\mathcal{M}, 2^c\}, Q_D \ll 2^t$
nonce-misuse resilience		
nonce-misuse resistance		
state-recovery security		

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nonce-misuse resilience	$\mathcal{N} \ll \min\{2^k/\mu, 2^c/\mathcal{M}\}$	$\mathcal{N} \ll \min\{2^k/\mu, 2^c/\mathcal{M}\}, \quad Q_D \ll 2^t$
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nonce-misuse resistance	—	$\mathcal{N} \ll \min\{2^k/\mu, 2^c/\mathcal{M}\}, \quad Q_D \ll 2^t$
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Simplified Numerical Interpretation

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nonce-respecting	$\mathcal{N} \ll \min\{2^k/\mu, 2^b/\mathcal{M}, 2^c\}$	$\mathcal{N} \ll \min\{2^k/\mu, 2^b/\mathcal{M}, 2^c\}$, $Q_D \ll 2^t$
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Application to Ascon-AEAD Parameters

- $(k, b, c, r, t) = \begin{cases} (128, 320, 256, 64, 128) \text{ for Ascon-128} \\ (128, 320, 192, 128, 128) \text{ for Ascon-128a} \\ (160, 320, 256, 64, 128) \text{ for Ascon-80pq} \end{cases}$
- Assume online complexity of $Q, \mathcal{M} \ll 2^{64}$ (could be taken higher)

Simplified Numerical Interpretation

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nonce-respecting	$\mathcal{N} \ll \min\{2^k/\mu, 2^b/\mathcal{M}, 2^c\}$	$\mathcal{N} \ll \min\{2^k/\mu, 2^b/\mathcal{M}, 2^c\}, Q_D \ll 2^t$
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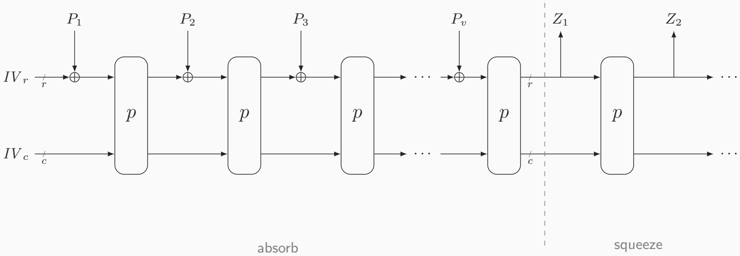
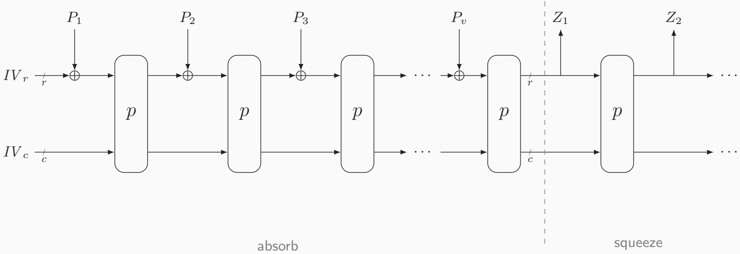
- Assume online complexity of $Q, \mathcal{M} \ll 2^{64}$ (could be taken higher)
- Generic security as long as $\mathcal{N} \ll 2^{128}/\mu$

(exceptions: $\mathcal{N} \ll 2^{160}/\mu$ for Ascon-80pq; $\mathcal{N} \ll 2^{96}$ for Ascon-128a under state-recovery)

Ascon-Hash/Ascon-(C)XOF

Ascon-Hash/Ascon-(C)XOF





Sponge [BDPV07]

- Permutation p on b bits
  - r is the rate
  - c is the capacity (security parameter)
- Output of ν bits (256 for Ascon-Hash, unlimited for the XOFs)

Generic Security of the Sponge

- Sponge indifferentiable from random up to bound $\mathcal{N}^2/2^c$ [BDPV08]

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- Sponge indifferentiable from random up to bound $\mathcal{N}^2/2^c$ [BDPV08]
- Security of sponge truncated to ν bits against classical attacks [AMP10]:

Collision resistance:	$\mathcal{N}^2/2^c + \mathcal{N}^2/2^{\nu+1}$
Second preimage resistance:	$\mathcal{N}^2/2^c + \mathcal{N}/2^\nu$
Preimage resistance:	$\mathcal{N}^2/2^c + \mathcal{N}/2^\nu$

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distance from sponge to RO
($\mathcal{N}$ is # primitive evaluations)

classical attacks against RO
($\mathcal{N}$ is # oracle evaluations)

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Second preimage resistance:	$\mathcal{N}^2/2^c + \mathcal{N}/2^{\nu}$	$\leftarrow$ attack in $\min\{2^{c/2}, 2^{\nu}\}$
Preimage resistance:	$\mathcal{N}^2/2^c + \mathcal{N}/2^{\nu}$	

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Preimage resistance:	$\mathcal{N}^2/2^c + \mathcal{N}/2^{\nu}$	$\leftarrow$ attack in $\min\{2^{\nu-r} + 2^{c/2}, 2^{\nu}\}$

distance from sponge to RO
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Second preimage resistance:	$\mathcal{N}^2/2^c + \mathcal{N}/2^{\nu}$	$\leftarrow$ attack in $\min\{2^{c/2}, 2^{\nu}\}$
~~Preimage resistance:~~	$\cancel{\underbrace{\mathcal{N}^2/2^c}_{\uparrow} + \underbrace{\mathcal{N}/2^{\nu}}_{\uparrow}}$	~~$\leftarrow$ attack in $\min\{2^{\nu-r} + 2^{c/2}, 2^{\nu}\}$~~

distance from sponge to RO ($\mathcal{N}$ is # primitive evaluations)

classical attacks against RO ($\mathcal{N}$ is # oracle evaluations)

- Attacks already described in [BDPV07]
- Tightened preimage resistance bound by Lefevre and Mennink [LM22]:

Preimage resistance: $\min\{\mathcal{N}/2^{\nu-r}, \mathcal{N}/2^{c/2}\} + \mathcal{N}/2^{\nu}$ $\leftarrow$ attack in $\min\{2^{\nu-r} + 2^{c/2}, 2^{\nu}\}$

Application to Ascon-Hash and Ascon-(C)XOF Parameters

- $(b, c, r, \nu) = \begin{cases} (320, 256, 64, 256) \text{ for Ascon-Hash} \\ (320, 256, 64, \infty) \text{ for Ascon-XOF} \\ (320, 256, 64, \infty) \text{ for Ascon-CXOF} \end{cases}$

Application to Ascon-Hash and Ascon-(C)XOF Parameters

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- Generic collision resistance as long as $\mathcal{N} \ll \min\{2^{128}, 2^{\nu/2}\}$

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Application to Ascon-Hash and Ascon-(C)XOF Parameters

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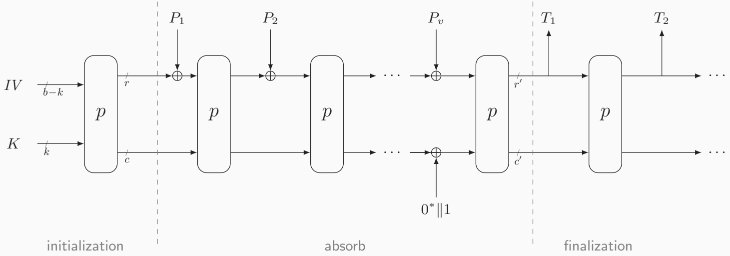
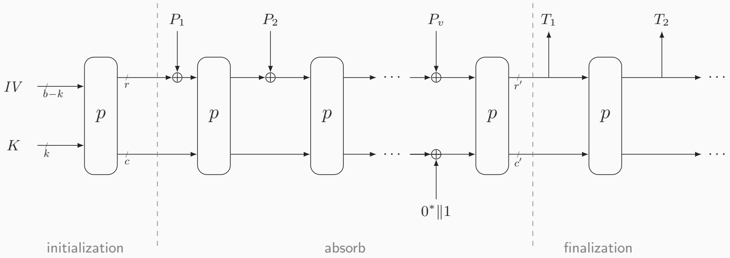
- Generic preimage resistance as long as $\mathcal{N} \ll \min\{2^{192}, 2^{\nu}\}$

Bonus: Ascon-PRF



Variant of Full-State Keyed Sponge [BDPV12, MRV15]

- Permutation p on b bits
  - r is the rate, c is the capacity (security parameter)



Variant of Full-State Keyed Sponge [BDPV12, MRV15]

- Permutation p on b bits
  - r is the rate, c is the capacity (security parameter)
- Domain separation to avoid squeezed tags being misused in absorption

FSKS and Ascon-PRF

FSKS and Ascon-PRF

2015 — Mennink et al. [MRV15]

Security of FSKS but with proof-inherent “multiplicity term”

FSKS and Ascon-PRF

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2017 — Daemen et al. [DMV17]
Generalized duplex
Applies to Ascon-PRF but with non-tight term $\mathcal{M}\mathcal{N}/2^c$

Generic Security of Ascon-PRF (1/2)

FSKS and Ascon-PRF

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Leakage resilience of generalized duplex
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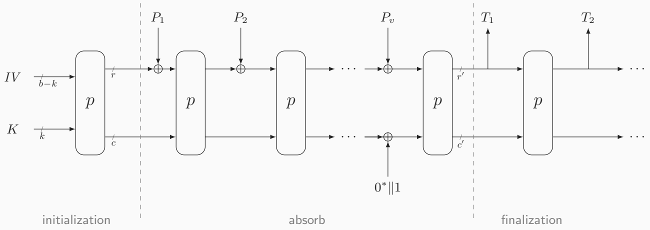
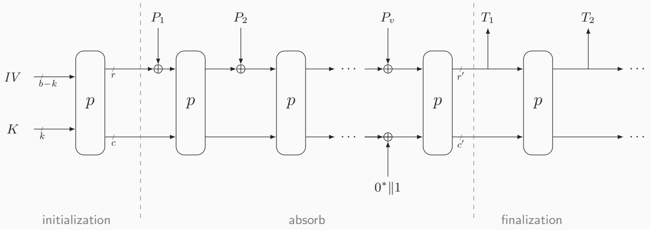
- 2023 Mennink [Men23]
  Duplex guide and improved analysis of Ascon-PRF
- 2025 Lefevre and Mennink (this work)
  Adapt bound of [Men23] with improved multicollision strategy



Generic Security Bound

- Ascon-PRF is multi-user secure up to bound $\frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{N}}{2^{c'}} + \frac{\mathcal{M}\mathcal{N}}{2^b}$



Generic Security Bound

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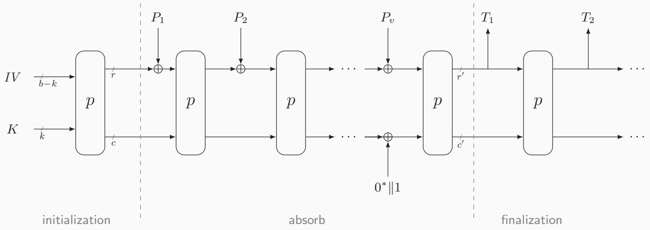
Application to Ascon-PRF Parameters

- $(k, b, c, r, c', r', t) = (128, 320, 64, 256, 192, 128, \infty)$
- Assume online complexity of $\mathcal{M} \ll 2^{64}$ (could be taken higher)



Generic Security Bound

- Ascon-PRF is multi-user secure up to bound $\frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{N}}{2^{c'}} + \frac{\mathcal{M}\mathcal{N}}{2^b}$

Application to Ascon-PRF Parameters

- $(k, b, c, r, c', r', t) = (128, 320, 64, 256, 192, 128, \infty)$
- Assume online complexity of $\mathcal{M} \ll 2^{64}$ (could be taken higher)
- Generic security as long as $\mathcal{N} \ll 2^{128}/\mu$

Conclusion

Conclusion

More in Paper: https://eprint.iacr.org/2024/1969

- Exact security models, settings, and discussions
- Discussion on multicollision bounding, assumption on $p, q, \ldots$
- All proofs and generic attacks

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What We Did Not Cover

- Related-key security and security for arbitrary key distributions
- Security under fault attacks
- Variant with nonce masking [DM24]
- Committing security $\longrightarrow$ next talk!

Conclusion

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