Radboud University

SoK: Security of the Ascon Modes

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Radboud University

Cryptography seminar of Rennes

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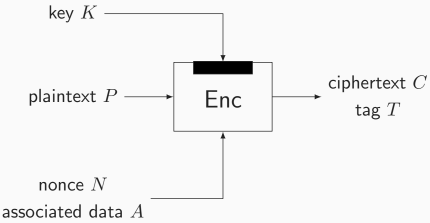
Introduction

Authenticated Encryption



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

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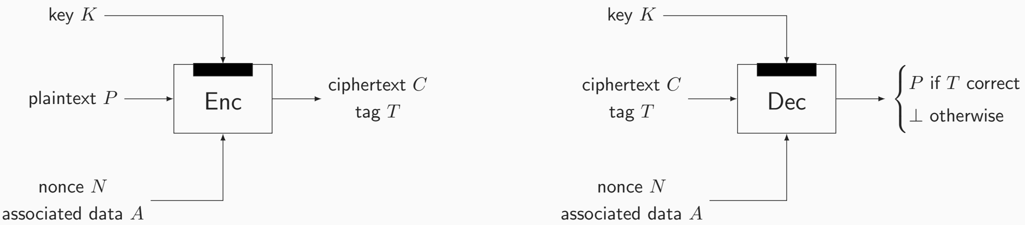

- Using key K:
  - Ciphertext C encrypts plaintext P
  - Tag T authenticates (N, A, P)
- Unwrapping needs to satisfy that
  - Plaintext disclosed if tag is correct
  - Plaintext is not leaked if tag is incorrect

CAESAR Competition

- 2014–2019
- Call for authenticated encryption scheme
- 57 submissions (of which ≈ 10 sponge/duplex-based)
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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

Ascon [DEMS21]

Authenticated Encryption

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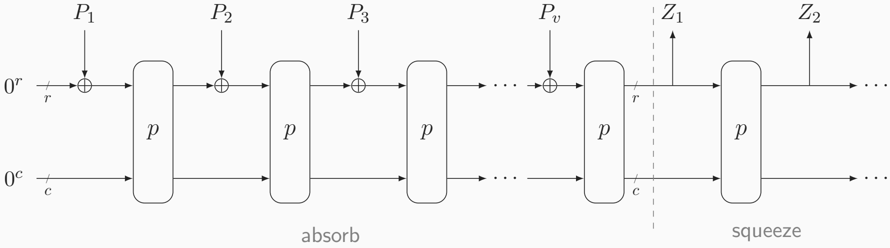
Hashing

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

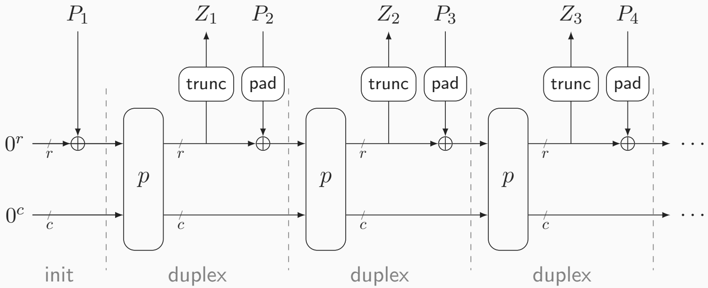
Ascon-AE

The Sponge Construction [BDPV07]



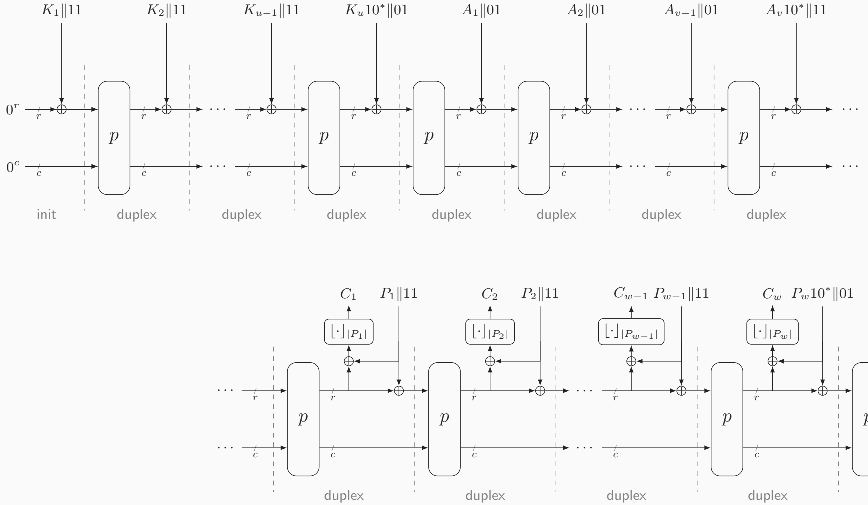
- Extendable Output Function (variable-length digest)
- State of size $b = r + c$ bits:
  - rate r (efficiency parameter)
  - capacity c (security parameter)
- $P_1 \| \cdots \| P_v$ is the message padded into r-bit blocks (e.g., 10^* padding)

The Duplex Construction [BDPV11]



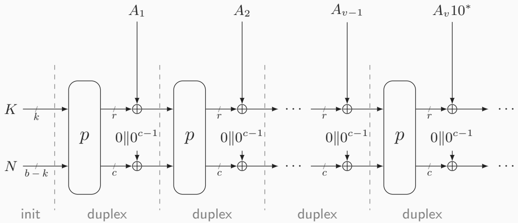
- Stateful version of sponge
- Interleaved absorb and squeeze
- Main application: authenticated encryption

SpongeWrap [BDPV11]

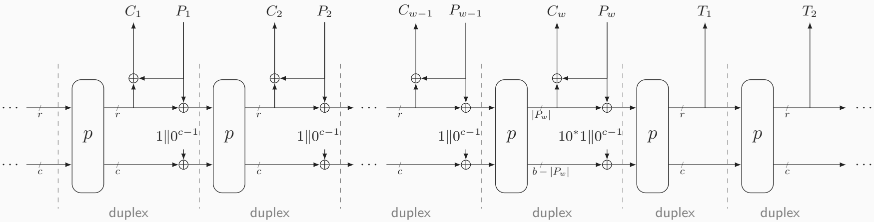


- SpongeWrap embeds duplex

MonkeySpongeWrap [Men23]



- State initialized using key and nonce
- Cleaned-up and synchronized domain separation
- Spill-over into inner part



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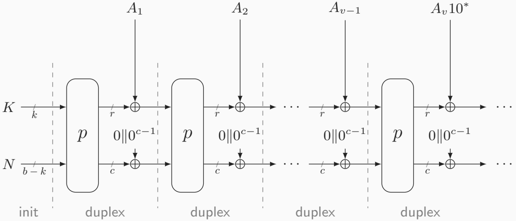

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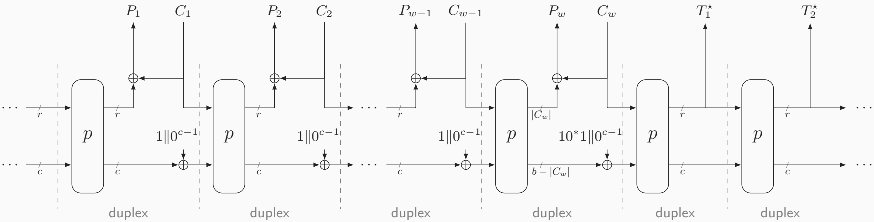

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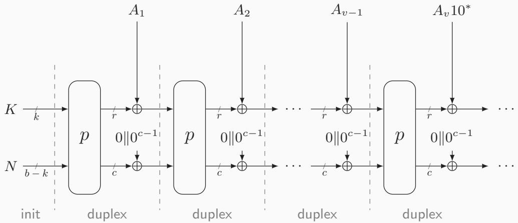

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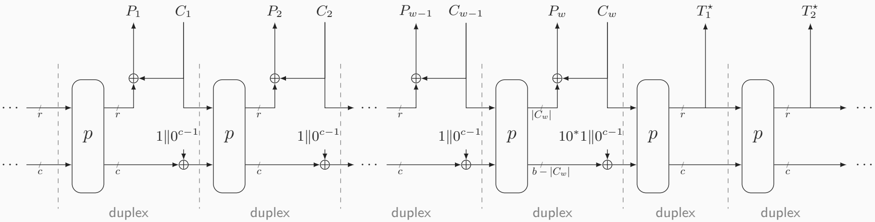
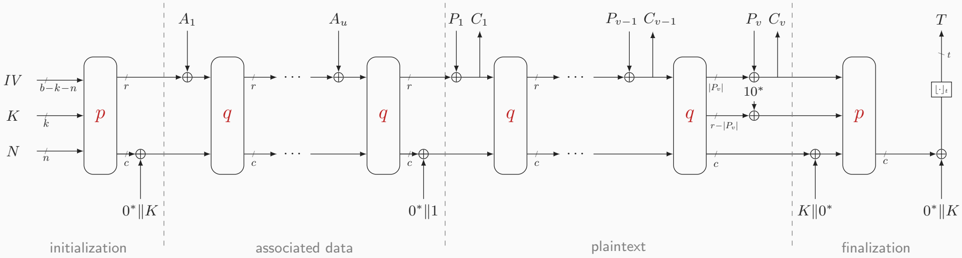
security depends on permutation strength, nonce conditions, and parameters





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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)

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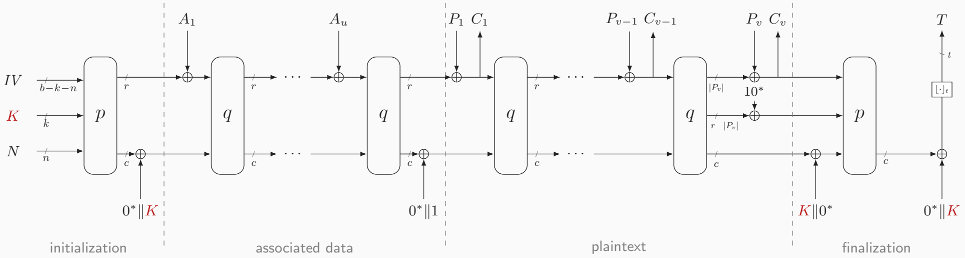

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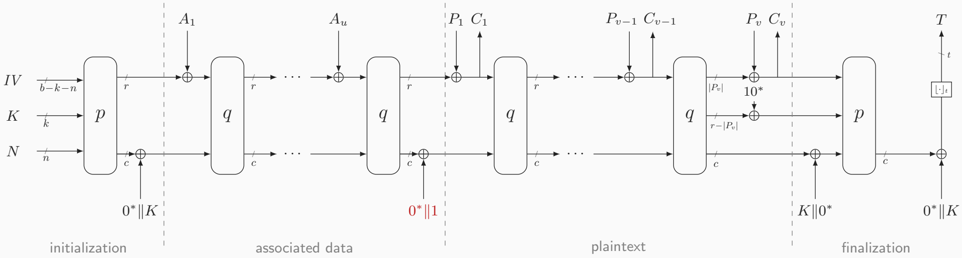

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- 2025 — Lefevre and Mennink (this work)
  - Let's clean this up!

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- We categorize existing lower and upper bounds
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- All results assume that $p = q$ is a random permutation

Conventional Security

1. **Nonce-respecting security** [BN00]
   - Confidentiality: distance $\left(\mathsf{Enc}_K^p, p\,;\, \$, p\right)$
   - Authenticity: $\mathbf{Pr}\left(\mathcal{A}\left[\mathsf{Enc}_K^p, \mathsf{Dec}_K^p, p\right] \text{ forges}\right)$
   - $\mathcal{A}$ never repeats the same nonce for encryption queries

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   - $\mathcal{A}$ never repeats the same nonce for encryption queries
2. **Nonce-misuse resistance** [RS06]
   - Same, but $\mathcal{A}$ may repeat the same nonce for encryption queries
   - Ascon does not achieve nonce-misuse confidentiality
   - In general, not achievable by one-pass AEs
   - Authenticity still achievable

❷ **Nonce-misuse resilience** [ADL17]

- Idea: challenge oracles for non-reused nonces only (but $\mathcal{A}$ may still repeat nonces in leaky oracles)
- Confidentiality: distance $\left(\mathsf{Enc}_K^p, \mathsf{LEnc}_K^p, p\,;\,\$, \mathsf{LEnc}_K^p, p\right)$
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Security Model (2/3)

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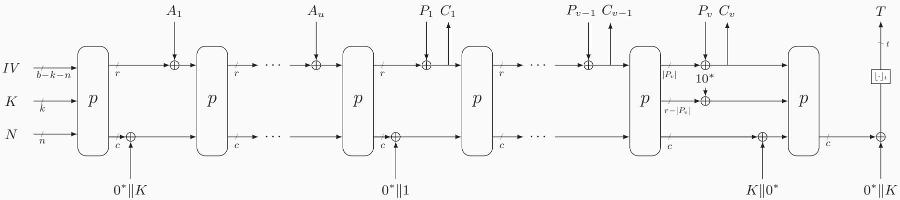
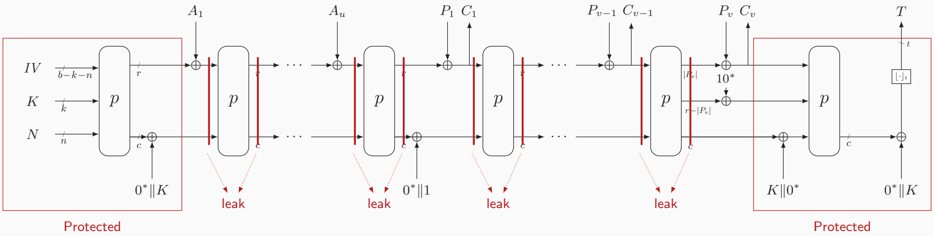
Leaky Security

❶ **Security under release of unverified plaintext** [ABL+14]

- Confidentiality is covered by plaintext awareness
  - Ascon does not achieve plaintext awareness
  - In general, not achievable by nonce-based length-preserving AEs
- Authenticity still achievable



- Ascon was designed to provide some security even if the internal permutation evaluations leak (e.g., via side channels)



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- Adverary's oracle access is similar to nonce-misuse resilience, where LEnc/LDec additionally leak leakage function's output

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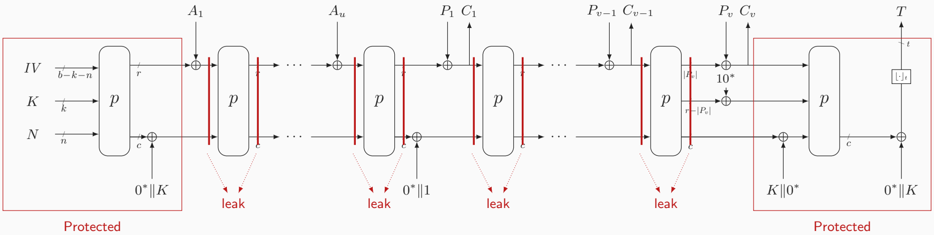

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❸ **State recovery**: the entire inner b-bit states leaks, adversary may reuse nonces

Overview of Results on Ascon-AE

nonce-respecting security
confidentiality
authenticity

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

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

leakage resilience, no leakage
confidentiality
authenticity

leakage resilience, limited
confidentiality
authenticity

leakage resilience, unlimited
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	$\frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$

core term $(\star)$

$\Longleftarrow$

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

$\Longleftarrow$

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

$\Updownarrow$

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

leakage resilience, limited	
confidentiality	
authenticity	

leakage resilience, unlimited	
confidentiality	
authenticity	

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

follows by equivalence

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	$\frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$

core term $(\star)$

$\Longleftarrow$

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

$\Longleftarrow$

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

$\Updownarrow$

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

leakage resilience, limited	
confidentiality	
authenticity	

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

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

analysis of [GPPS19] incomplete
and in different model
new: security bounds
and 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	$\frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$

core term $(\star)$

$\Longleftarrow$

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

$\Longleftarrow$

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

$\Updownarrow$

leakage resilience, no leakage	
confidentiality	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c}$
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	$(\star) + \frac{\mathcal{M}\mathcal{N}}{2^c} + \min\left\{\frac{\mathcal{N}^2}{2^c}, \frac{Q\mathcal{N}}{2^k}\right\}$

$\Uparrow \quad \Downarrow_{\cap}$

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

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

follows by implication

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	$\frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$

core term $(\star)$

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

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

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

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

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

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

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

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

Overview of Results on Ascon-AE

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

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

new: security bounds and matching attacks

$\Longleftarrow$

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

$\Longleftarrow$

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

$\Updownarrow$

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

$\Uparrow$

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

$\Uparrow \quad \Downarrow_{\mathrm{c}}$

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

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

$\Uparrow^{\mathrm{auth}}$

$\Longleftarrow$

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

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	$\mathcal{N} \ll \min\{2^k/\mu, 2^c/\mathcal{M}\}$	$\mathcal{N} \ll \min\{2^k/\mu, 2^c/\mathcal{M}\}$, $Q_D \ll 2^t$
nonce-misuse resistance	—	$\mathcal{N} \ll \min\{2^k/\mu, 2^c/\mathcal{M}\}$, $Q_D \ll 2^t$
state-recovery security	—	$\mathcal{N} \ll \min\{2^k/\mu, 2^{c/2}\}$, $Q_D \ll 2^t$

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	$\mathcal{N} \ll \min\{2^k/\mu, 2^c/\mathcal{M}\}$	$\mathcal{N} \ll \min\{2^k/\mu, 2^c/\mathcal{M}\}, \quad Q_D \ll 2^t$
nonce-misuse resistance	—	$\mathcal{N} \ll \min\{2^k/\mu, 2^c/\mathcal{M}\}, \quad Q_D \ll 2^t$
state-recovery security	—	$\mathcal{N} \ll \min\{2^k/\mu, 2^{c/2}\}, \quad Q_D \ll 2^t$

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 $Q, \mathcal{M} \ll 2^{64} \cdot \mu$

Simplified Numerical Interpretation

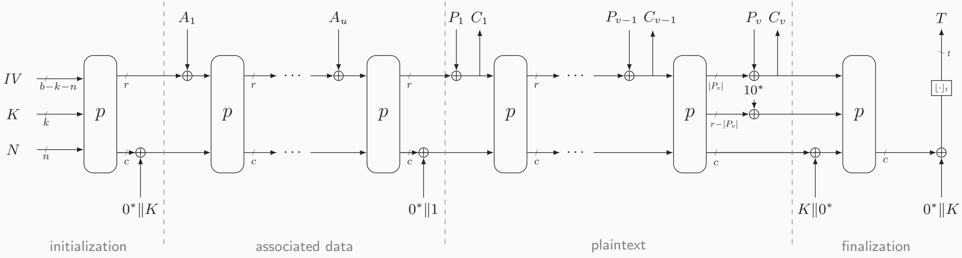
setting	confidentiality as long as	authenticity as long as
nonce-respecting	$\mathcal{N} \ll \min\{2^k/\mu, 2^b/\mathcal{M}, 2^c\}$	$\mathcal{N} \ll \min\{2^k/\mu, 2^b/\mathcal{M}, 2^c\}, Q_D \ll 2^t$
nonce-misuse resilience	$\mathcal{N} \ll \min\{2^k/\mu, 2^c/\mathcal{M}\}$	$\mathcal{N} \ll \min\{2^k/\mu,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

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 $Q, \mathcal{M} \ll 2^{64} \cdot \mu$
- Generic security as long as $\mathcal{N} \ll 2^{128}/\mu$

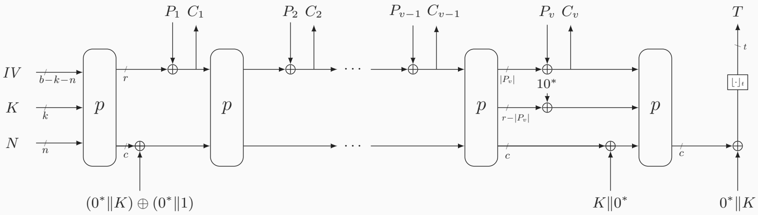
  (exceptions: $\mathcal{N} \ll 2^{160}/\mu$ for Ascon-80pq; $\mathcal{N} \ll 2^{96}$ for Ascon-128a under state-recovery)

Teaser: How to Forge (1/6)



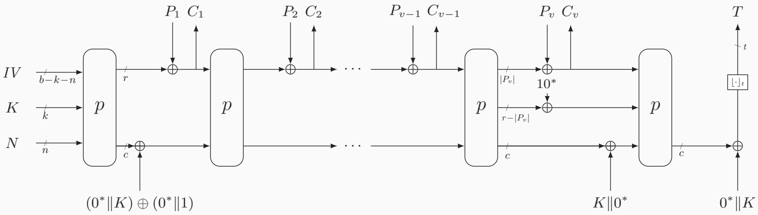
General Goal: Forgery

- Observe multiple evaluations $\mathsf{Enc}_K(N, A, P) = (C, T)$
- Output a new tuple (N, A, C, T) for which Dec_K does not return $\perp$



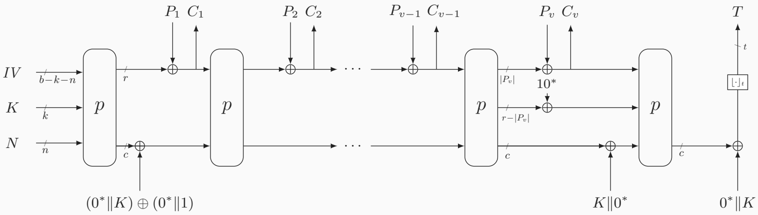
General Setup

- Adversary ignores associated data



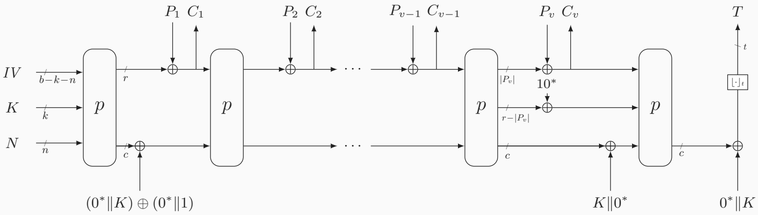
General Setup

- Adversary ignores associated data
- Adversary can make $\mathcal{N}$ queries to p,
  $\mathcal{M}$ construction queries,
  Q_D forgery attempts



Nonce-Respecting Adversary

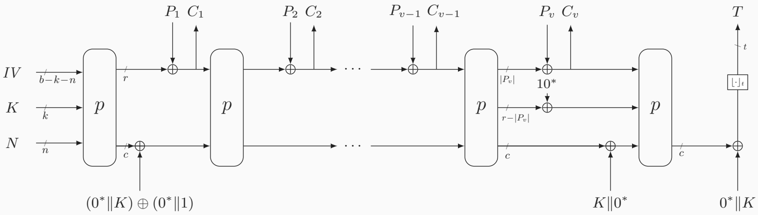
$$(\star) = \frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$$



Nonce-Respecting Adversary

$$(\star) = \frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$$

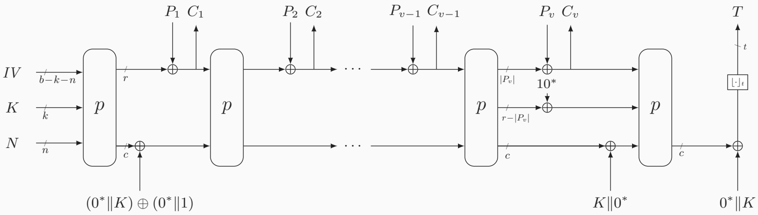
- First term corresponds to random tag guessing:
  - Any guess succeeds with probability $1/2^t$



Nonce-Respecting Adversary

$$(\star) = \frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$$

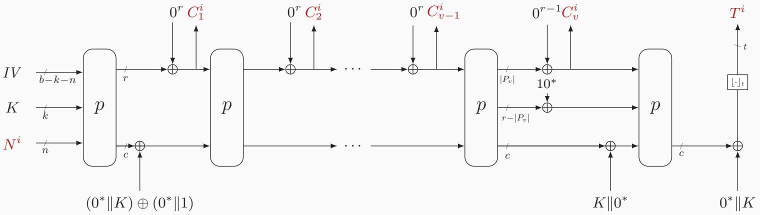
- First term corresponds to random tag guessing:
  - Any guess succeeds with probability $1/2^t$
- Second term corresponds to random key guessing:
  - Any guess succeeds with probability $\mu/2^k$ (as there are μ keys)



Nonce-Respecting Adversary

$$(\star) = \frac{Q_D}{2^t} + \frac{\mu \mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$$

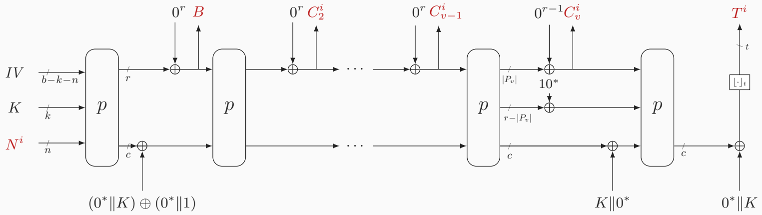
- Last two terms correspond to following attack:



Nonce-Respecting Adversary

$$(\star) = \frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$$

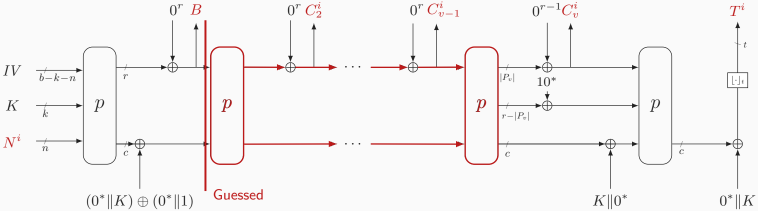
- Last two terms correspond to following attack:
  - Make $\mathcal{M}$ queries for plaintext 0^{rv-1}, get ciphertexts $C_1^i\|\cdots\|C_v^i$
  - Looking ahead, v is a logarithmic factor



Nonce-Respecting Adversary

$$(\star) = \frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$$

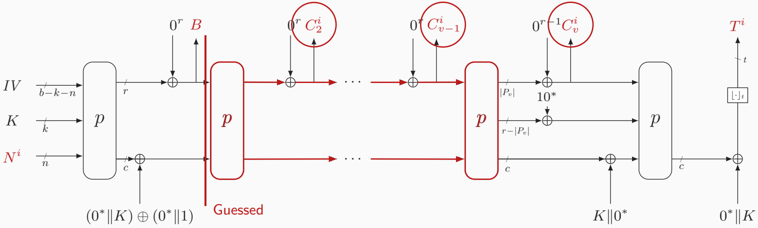
- Last two terms correspond to following attack:
  - Let $B \in \{0,1\}^r$ be the most frequent ciphertext block C^i_1
  - Query $p^f(B\|X_j)$, for $f = 1, \ldots, v-1$ and $\mathcal{N}$ random $X_j \in \{0,1\}^c$
  - Total cost: $\mathcal{N} \times (v-1)$ permutation queries (can be simplified)



Nonce-Respecting Adversary

$$(\star) = \frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$$

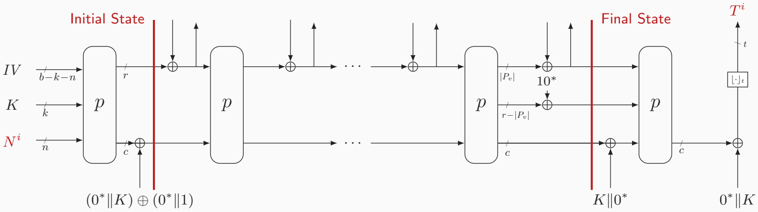
- Last two terms correspond to following attack:
  - With probability $\approx \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$, adversary guesses internal state



Nonce-Respecting Adversary

$$(\star) = \frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$$

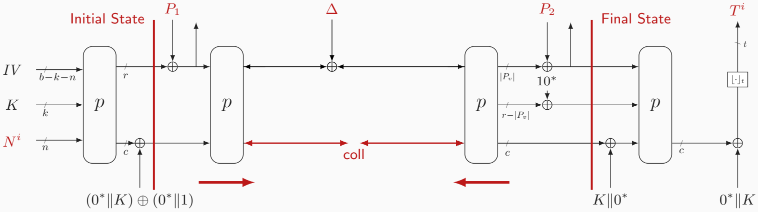
- Last two terms correspond to following attack:
  - With probability $\approx \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$, adversary guesses internal state
  - If v is large enough (e.g., $\approx \lceil b/r \rceil$), false positives can be discarded with high probability



Nonce-Respecting Adversary

$$(\star) = \frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$$

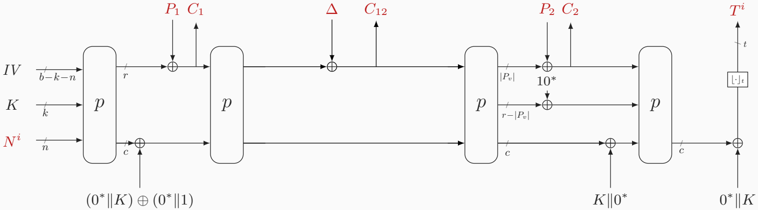
- Last two terms correspond to following attack:
  - Final step: connect initial and final states with a different plaintext



Nonce-Respecting Adversary

$$(\star) = \frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$$

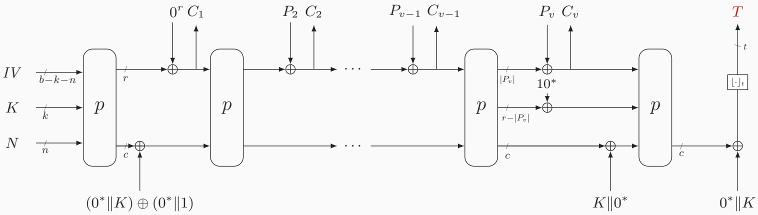
- Last two terms correspond to following attack:
  - Final step: connect initial and final states with a different plaintext
  - Boils down to finding inner collisions, success probability $\approx \frac{\mathcal{N}(\mathcal{N}-1)}{2^{c+1}}$



Nonce-Respecting Adversary

$$(\star) = \frac{Q_D}{2^t} + \frac{\mu\mathcal{N}}{2^k} + \frac{\mathcal{M}\mathcal{N}}{2^b} + \frac{\mathcal{N}}{2^c}$$

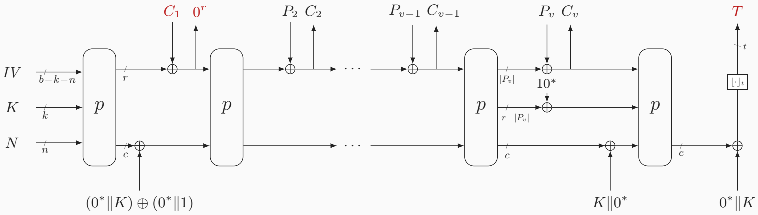
- Last two terms correspond to following attack:
  - Final step: connect initial and final states with a different plaintext
  - Boils down to finding inner collisions, success probability $\approx \frac{\mathcal{N}(\mathcal{N}-1)}{2^{c+1}}$
  - The input $(N^i, (C_1\|C_{12}\|C_2), T^i)$ is a valid forgery



$$(\star) + \frac{\mathcal{MN}}{2^c}$$

Nonce-Misuse Resistance Adversary

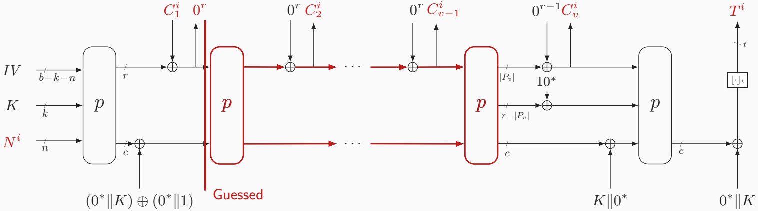
- This time the adversary can re-use nonces



Nonce-Misuse Resistance Adversary

$$(\star) + \frac{\mathcal{MN}}{2^c}$$

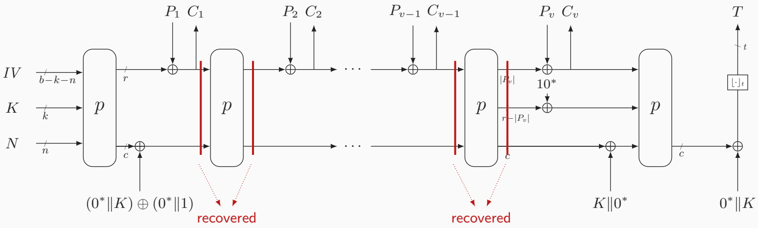
- This time the adversary can re-use nonces
- Allows overwriting the outer parts to a value of its choice



Nonce-Misuse Resistance Adversary

$$(\star) + \frac{\mathcal{MN}}{2^c}$$

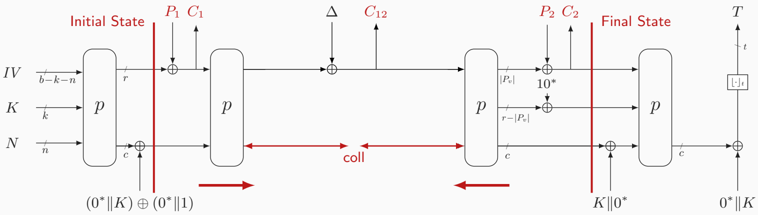
- This time the adversary can re-use nonces
- Allows overwriting the outer parts to a value of its choice
- Same strategy as before can be applied, but state guessing step sped up
  - Success probability of $\approx \frac{\mathcal{MN}}{2^c}$



State-Recovery Adversary

$$(\star) + \frac{\mathcal{N}^2}{2^c}$$

- The internal states leak



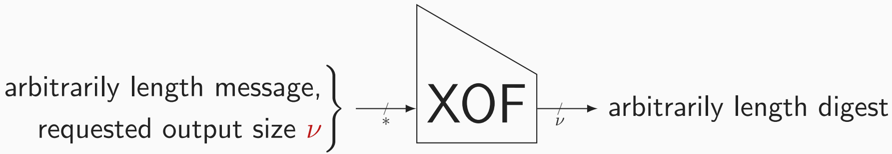
$$(\star) + \frac{\mathcal{N}^2}{2^c}$$

State-Recovery Adversary

- The internal states leak
- It just remains to apply the last step of previous attacks
  - Success probability $\approx \frac{\mathcal{N}(\mathcal{N}-1)}{2^{c+1}}$

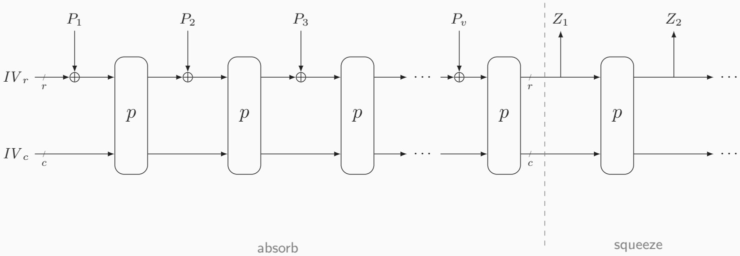
Ascon-Hash/Ascon-(C)XOF

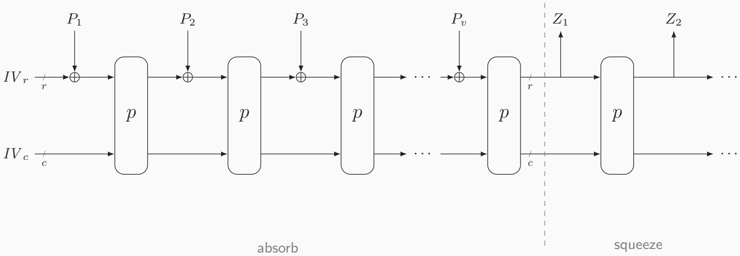
Modern Definition of Hashing



- Function XOF from $\{0,1\}^*$ to $\{0,1\}^\infty$
  - Variable-length input
  - Variable-length output
  - User specifies output length ν when calling the function

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)

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

Generic Security of the Sponge

- 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:	$\mathcal{N}^2/2^c + \mathcal{N}/2^{\nu}$
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distance from sponge to RO
($\mathcal{N}$ is # primitive evaluations)

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

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

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

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

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

Bonus: Ascon-PRF

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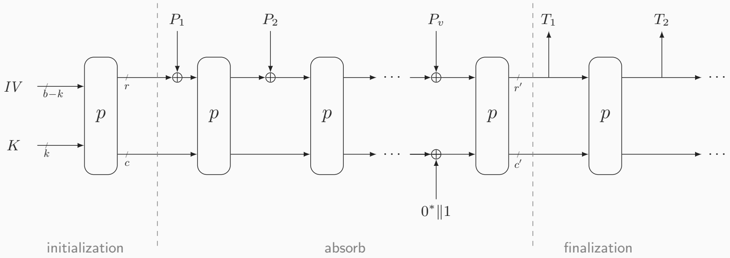

Variant of Full-State Keyed Sponge [BDPV12, MRV15]

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

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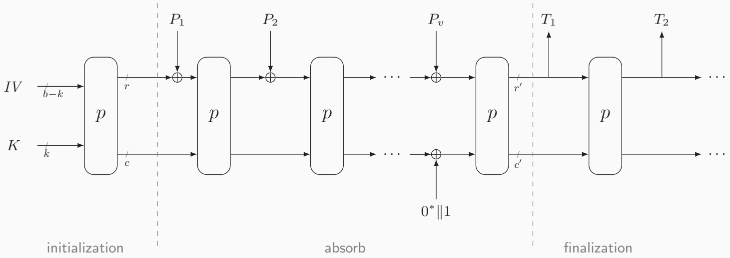

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- Permutation p on b bits
  - r is the rate, c is the capacity (security parameter)
- Domain separation to avoid squeezed tags being misused in absorption

FSKS and Ascon-PRF

Generic Security of Ascon-PRF (1/2)

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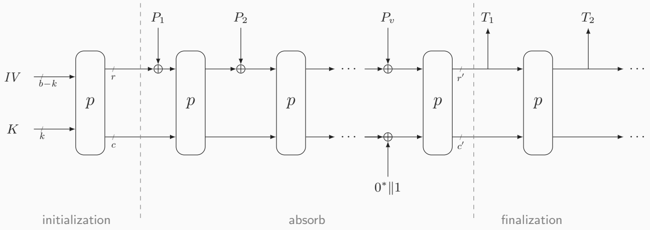
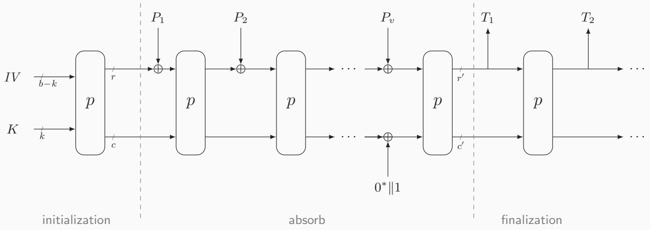
- 2023 — Mennink [Men23]
  Duplex guide and improved analysis of Ascon-PRF
- 2025 — Lefevre and Mennink (this work)
  Adapt bound of [Men23] with improved multicollision strategy



Generic Security Bound

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



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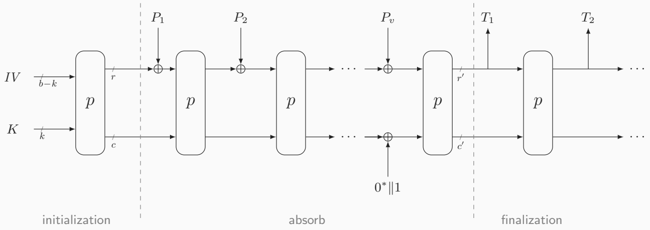
Application to Ascon-PRF Parameters

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



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- Assume online complexity of $\mathcal{M} \ll 2^{64} \cdot \mu$ (could be taken higher)
- Generic security as long as $\mathcal{N} \ll 2^{128}/\mu$

Conclusion

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

- Exact security models, settings, and discussions
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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]
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Thank you for your attention!

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