

# Standardization of Ascon Family

Meltem Sönmez Turan  
NIST Lightweight Cryptography Team

# Overview of the Talk

**I.** NIST lightweight cryptography standardization process

**II.** Finalists

**III.** Evaluation of finalists

**IV.** Selection & standardization





- Part of US Department of Commerce
- Founded in 1901, known as the National Bureau of Standards (NBS) prior to 1988

## MISSION

to promote U.S. innovation and industrial competitiveness by advancing measurement science, standards, and technology in ways that enhance economic security and improve our quality of life.



**3,400+**

FEDERAL  
EMPLOYEES



**3,500+**

ASSOCIATES



**5**

NOBEL PRIZES

Laboratory Programs → Information Technology Lab → Computer Security Division

## Developing Crypto Standards

- International “competitions” e.g., AES, SHA-3, PQC, Lightweight Crypto
- Adoption of existing standards e.g., RSA, HMAC
- Open call for proposals: e.g., block cipher modes of operations

## CSD Publications

- Federal Information Processing Standards (FIPS): Specify approved crypto standards.
- NIST Special Publications (SPs): Guidelines, technical specifications, recommendations etc.
- NIST Internal or Interagency Reports (IR): Reports of research findings.

## Principles

Transparency, openness, balance, integrity, technical merit, global acceptability, usability, continuous improvement, innovation and intellectual property.

# Part I – NIST Lightweight Cryptography Standardization Process

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U.S. DEPARTMENT OF COMMERCE



**Initial Phase**  
**(July 2015 – August 2018)**



**Submission Call**  
**(August 2018 – April 2019)**



**Round 1**  
**(April 2019 – August 2019)**



**Round 2**  
**(August 2019 – March 2021)**



**Final Round**  
**(March 2021 – February 2023)**



**Initial Phase**  
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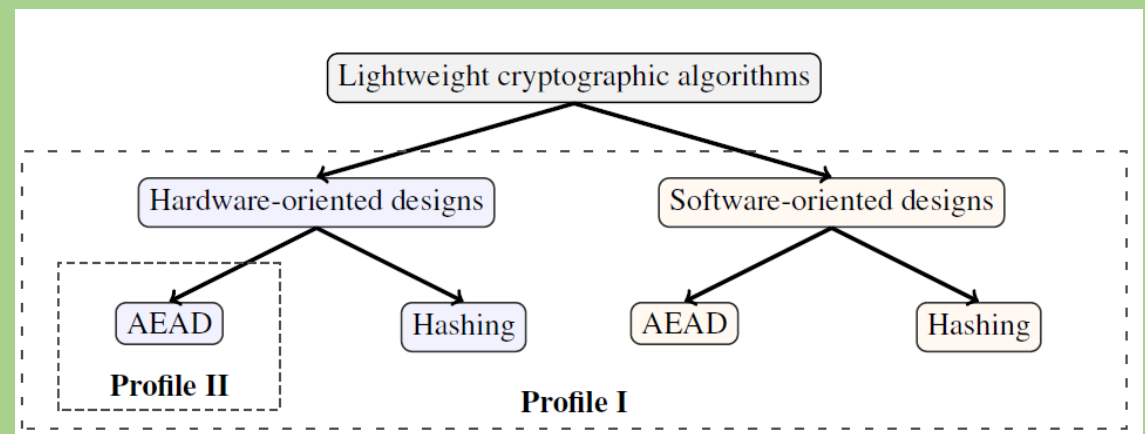
## Workshops:

- First Lightweight Cryptography Workshop  
July 20 – 21, 2015
- Second Lightweight Cryptography Workshop  
October 17 – 18, 2016

to get feedback on target applications, industry need, requirements, etc.

## Publications:

- NISTIR 8114 *Report on Lightweight Cryptography*
- (White paper, retired) *Profiles for the Lightweight Cryptography Standardization Process*





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**Final Round**  
(March 2021 – February 2023)

**Process:** Public competition-like process with multiple rounds like AES, SHA-3 and PQC standardization.

**Scope:** Authenticated Encryption and (optional) hashing for constrained software and hardware environments

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In August 2018, NIST published '*Submission Requirements and Evaluation Criteria for the Lightweight Cryptography Standardization Process*'.

**Submission deadline:** February 2019





**Initial Phase**  
(July 2015 – August 2018)



**Submission Call**  
(August 2018 – April 2019)



**Round 1**  
(April 2019 – August 2019)



**Round 2**  
(August 2019 – March 2021)



**Final Round**  
(March 2021 – February 2023)

Around 4 months

56 First-round candidates

Evaluation of the candidates were done based on their security

- e.g., distinguishing attacks, practical tag forgeries, domain separation issues, new designs with no third-party analysis etc.

**NIST IR 8268** explains how 32 candidates (out of 56) were selected to move forward to the second round.

NISTIR 8268

**Status Report on the First Round of the  
NIST Lightweight Cryptography  
Standardization Process**

Meltem Sonmez Turan  
Kerry A. McKay  
Çağdaş Çalik  
Donghoon Chang  
Larry Bassham

This publication is available free of charge from:  
<https://doi.org/10.6028/NIST.IR.8268>

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**Initial Phase**  
(July 2015 – August 2018)



**Submission Call**  
(August 2018 – April 2019)



**Round 1**  
(April 2019 – August 2019)



**Round 2**  
(August 2019 – March 2021)



**Final Round**  
(March 2021 – February 2023)

Around 20 months

32 Second-round candidates

**Workshops:**

- Third Lightweight Cryptography Workshop  
November 4 – 6, 2019
- Fourth Lightweight Cryptography Workshop 2016  
October 19 – 21, 2020

**NIST IR 8369** explains how  
10 finalists were selected  
to move forward to  
the final round.

NISTIR 8369

**Status Report on the Second Round of  
the NIST Lightweight Cryptography  
Standardization Process**

Meltem Sönmez Turan  
Kerry McKay  
Donghoon Chang  
Çağdaş Çalik  
Lawrence Bassham  
Jinkeon Kang  
John Kelsey

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**Initial Phase**  
(July 2015 – August 2018)



**Submission Call**  
(August 2018 – April 2019)



**Round 1**  
(April 2019 – August 2019)



**Round 2**  
(August 2019 – March 2021)



**Final Round**  
(March 2021 – February 2023)

Around 24 months

10 finalists:

Ascon

Photon-Beetle

Elephant

Romulus

GIFT-COFB

Sparkle

Grain-128AEAD

TinyJambu

ISAP

Xoodoo

**NIST IR 8454** explains  
the selection of Ascon.

NIST Internal Report 8454

Status Report on the Final Round of  
the NIST Lightweight Cryptography  
Standardization Process

Meltem Sönmez Turan  
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Donghoon Chang  
Lawrence E. Bassham  
Jinkeon Kang  
Noah D. Waller  
John M. Kelsey  
Deukjo Hong



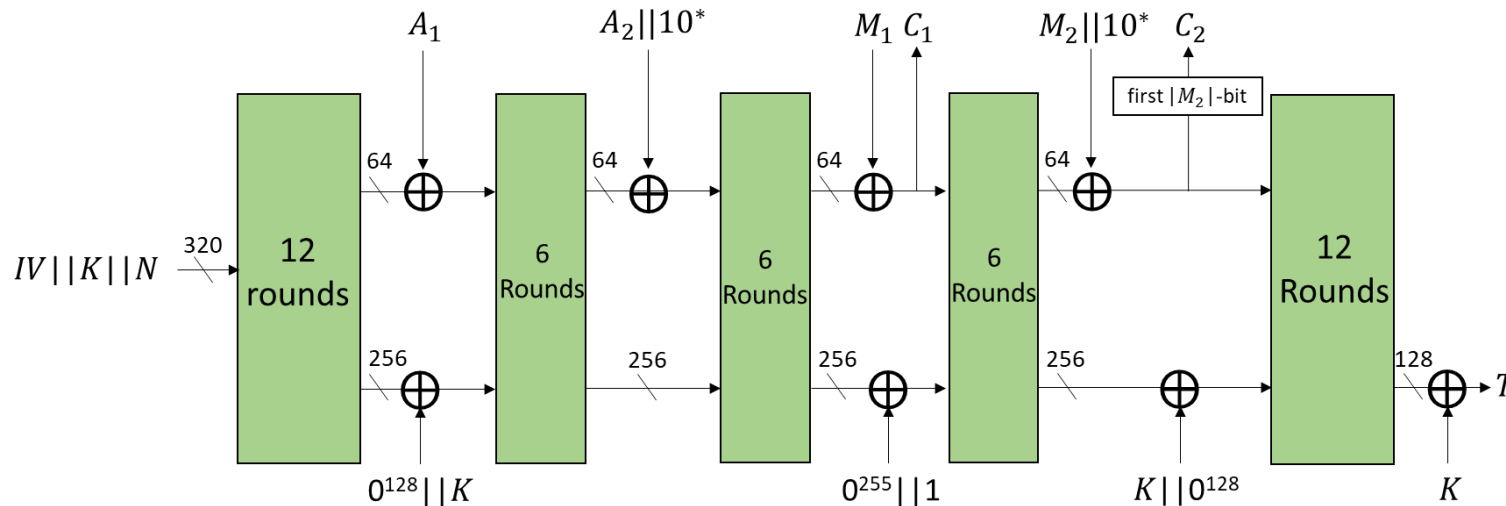
# Part II – Finalists



# ASCON

- Permutation-based (320-bit) AEAD and hashing scheme (fixed or variable output length)
- MonkeyDuplex mode with keyed initialization and finalization
- No design tweak, new variant added in the final round
- Included in the final portfolio of CAESAR for lightweight authenticated encryption

	Variant	Parameter sizes
AEAD	<b>Ascon-128</b>	128-bit key/nonce/tag
	Ascon-128a	128-bit key/nonce/tag
	Ascon-80-pq	160-bit key, 128-bit nonce/tag
Hash	<b>Ascon-hash</b>	256-bit digest
	Ascon-hasha	256-bit digest
XOF	Ascon-XOF	Arbitrary length digest
	Ascon-XOFa	Arbitrary length digest

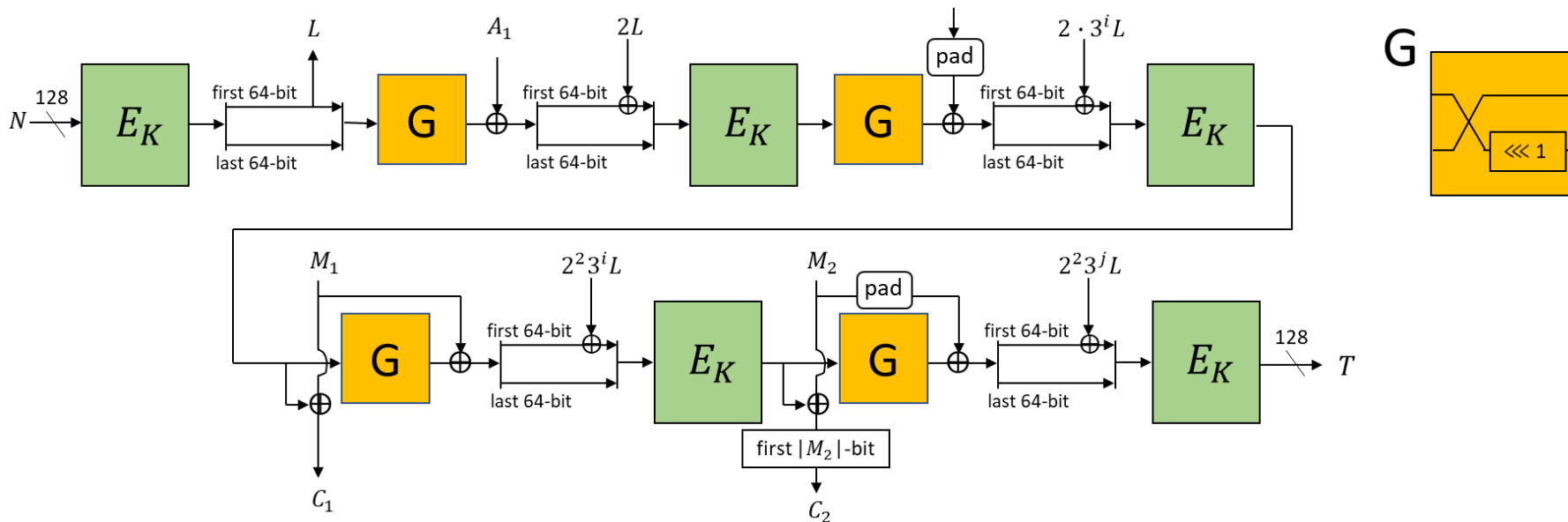




# GIFT-COFB

- Block-cipher (GIFT-128) based AEAD scheme
- Combined Feedback (COFB) mode
- No design tweak

Variant	Parameter sizes
<b>Gift-COFB</b>	128-bit key/nonce/tag



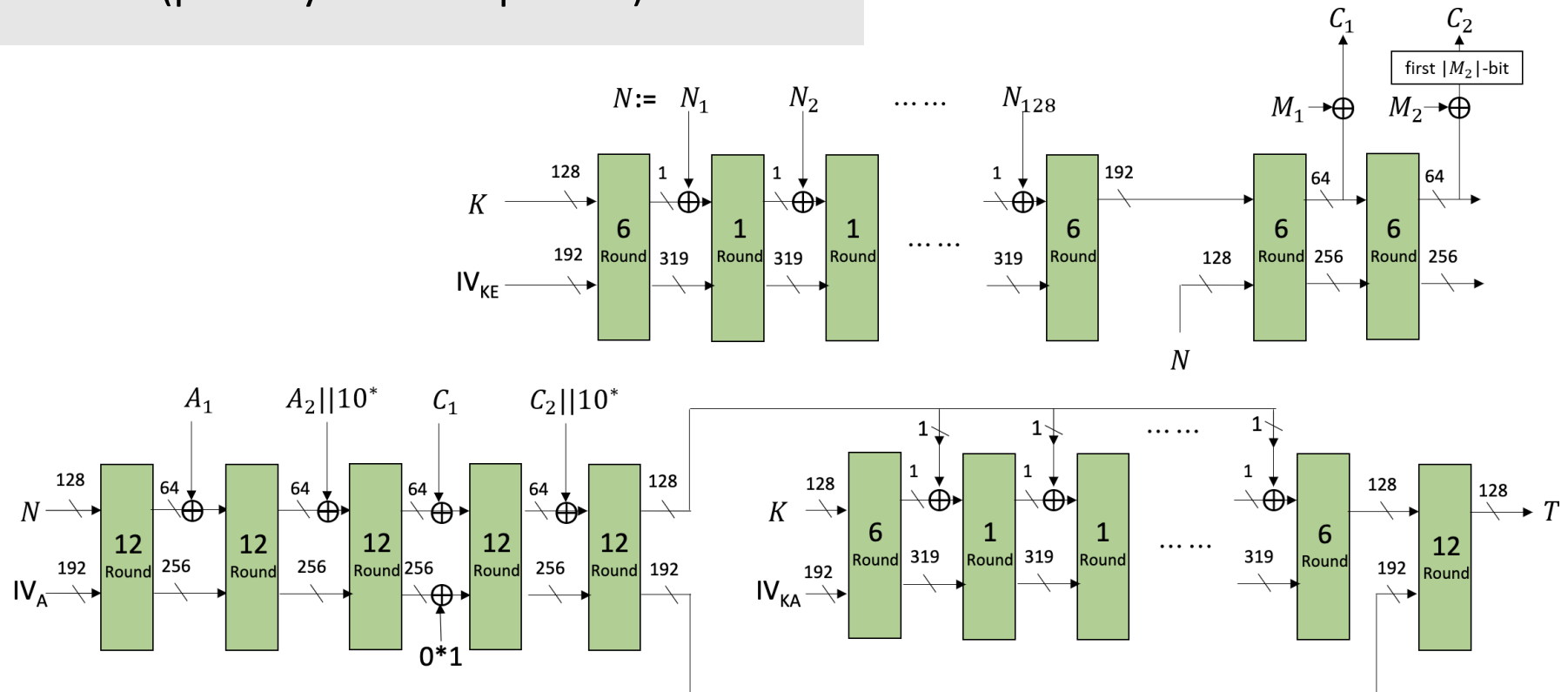




# ISAP

- Permutation-based (Ascon and Keccak permutations) AEAD scheme
- Can be paired with Ascon Hash
- Nonce-based Encrypt-then-MAC mode
- Algorithm-level security against implementation attacks
- No design tweak (primary variant updated)

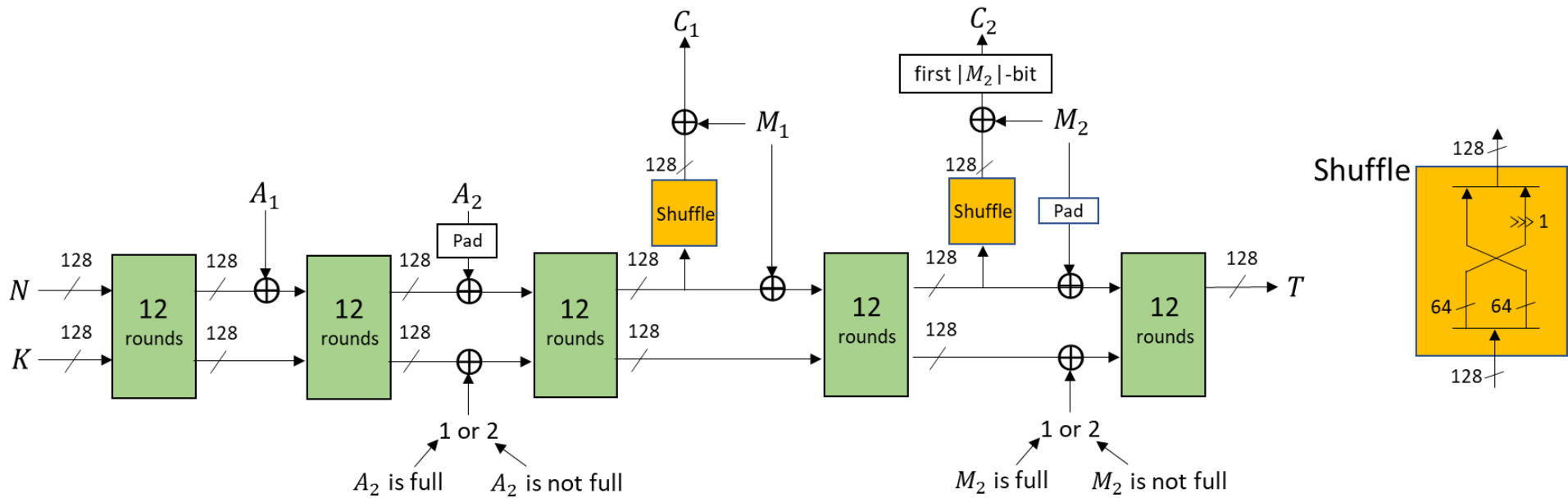
Variant	Parameter sizes
ISAP-A-128a	128-bit key/nonce/tag
ISAP-K-128a	128-bit key/nonce/tag
ISAP-A-128	128-bit key/nonce/tag
ISAP-K-128	128-bit key/nonce/tag



# PHOTON-BEETLE

- Family of permutation-based (256-bit Photon permutation) AEAD & hashing scheme
- Sponge-like mode with a combined feedback.
- No design tweak

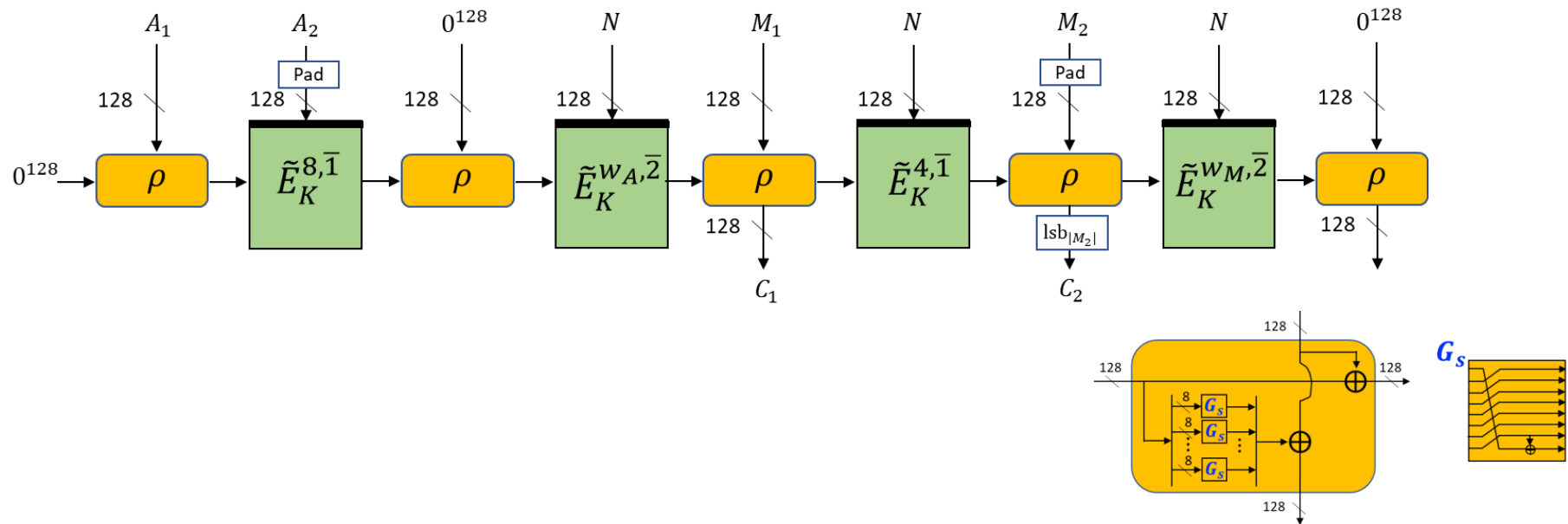
	Variant	Parameter sizes
AEAD	Photon-Beetle-AEAD[128]	128-bit key/nonce/tag
	Photon-Beetle-AEAD[32]	128-bit key/nonce/tag
Hash	Photon-Beetle-Hash[32]	256-bit digest



# ROMULUS

- Family of tweakable-block-cipher (Skinny) based AEAD & hashing
- Romulus-N: rate-1 TBC-based combined feedback, Romulus-M: MAC-then-Encrypt
- Nonce-misuse and nonce-respecting variants
- Design tweak to reduce the number of rounds from 56 to 40, removal of non-primary variants, addition of new variants.

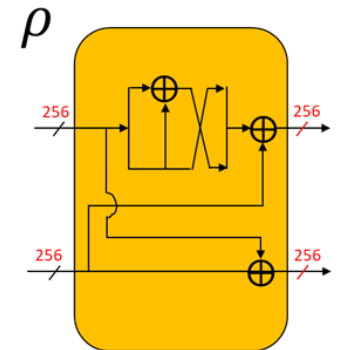
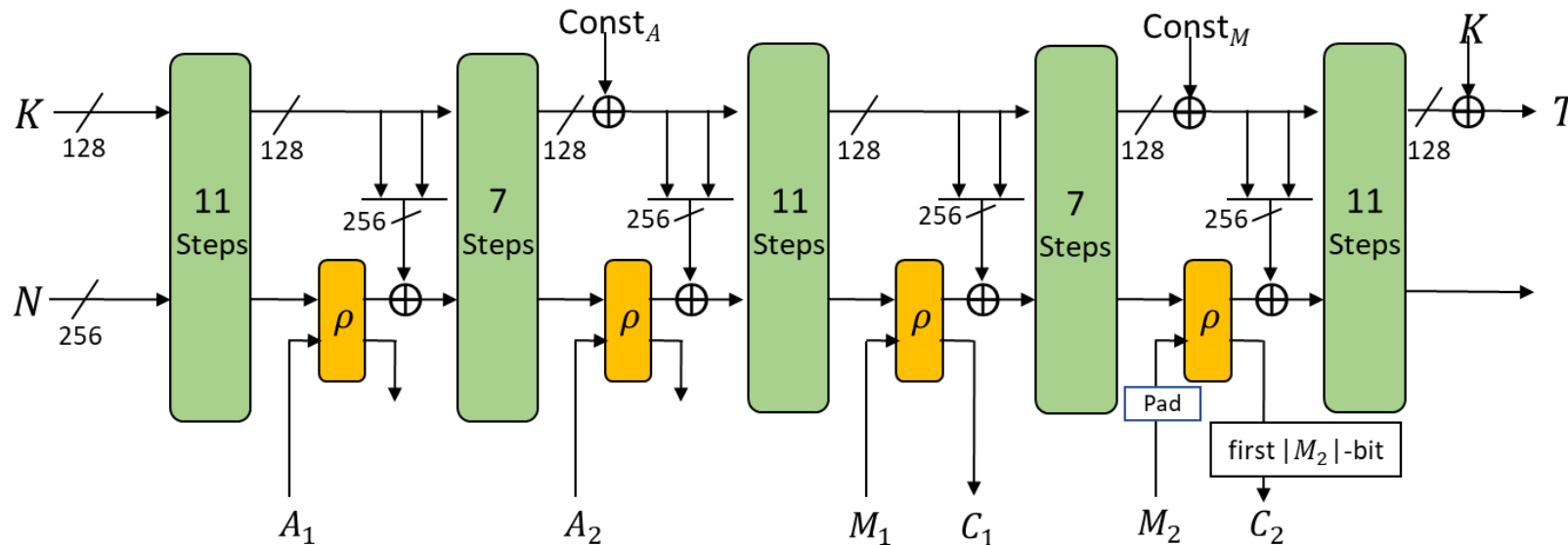
	Variant	Parameter sizes
AEAD	Romulus-N	128-bit key/nonce/tag
	Romulus-M	128-bit key/nonce/tag
	Romulus-T	128-bit key/nonce/tag
Hash	Romulus-H	256-bit digest



# SPARKLE

- Family of permutation-based AEAD (SCHWAEMM) and hashing (ESCH)
- ARX based design
- Sponge construction with combined feedback
- Tweak to change the primary variant

	Variant	Parameter sizes
AEAD	<b>SCHWAEMM256-128</b>	128-bit key/tag, 256-bit nonce
	SCHWAEMM128-128	128-bit key/nonce/tag
	SCHWAEMM192-192	192-bit key/nonce/tag
	SCHWAEMM256-256	256-bit key/nonce/tag
Hash	<b>ESCH256</b>	256-bit digest
	ESCH384	384-bit digest
XOF	XOESCH256	Arbitrary length digest
	XOESCH384	Arbitrary length digest

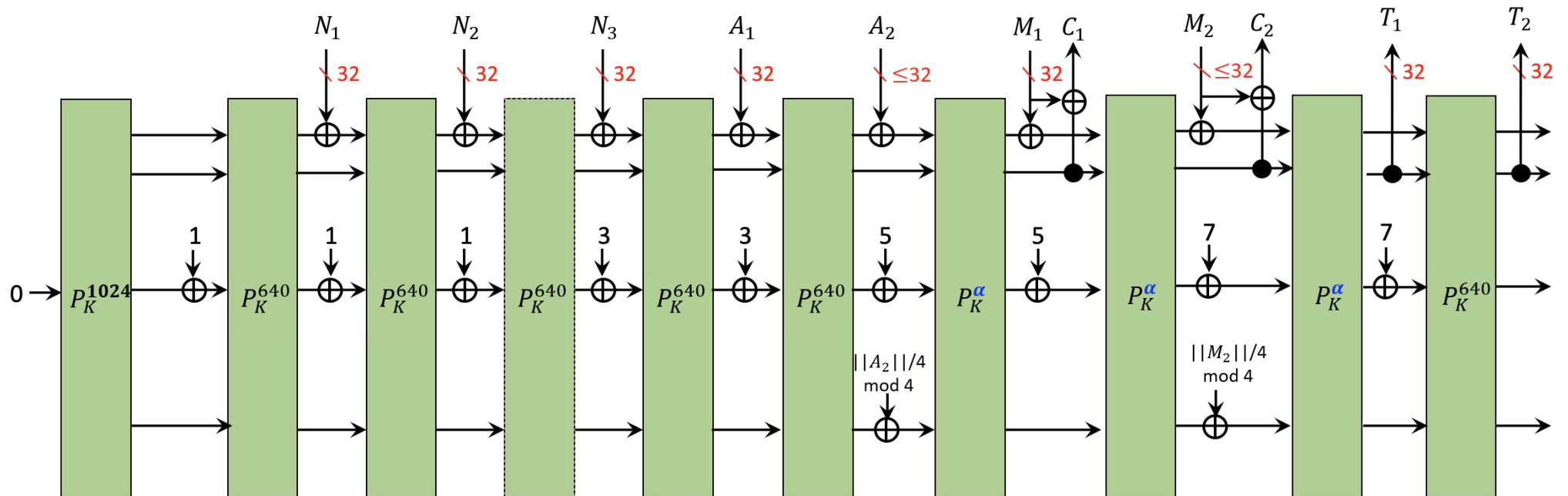




# TINYJAMBU

- Keyed-permutation based AEAD scheme
- Uses 128-bit nonlinear feedback shift register
- Inspired by JAMBU (CAESAR candidate)
- Design tweak: increase in number of rounds to improve security margin.

Variant	Parameter sizes
<b>TinyJambu-128</b>	128-bit key, 96-bit nonce, 64-bit tag
TinyJambu-192	192-bit key, 96-bit nonce, 64-bit tag
TinyJambu-256	256-bit key, 96-bit nonce, 64-bit tag

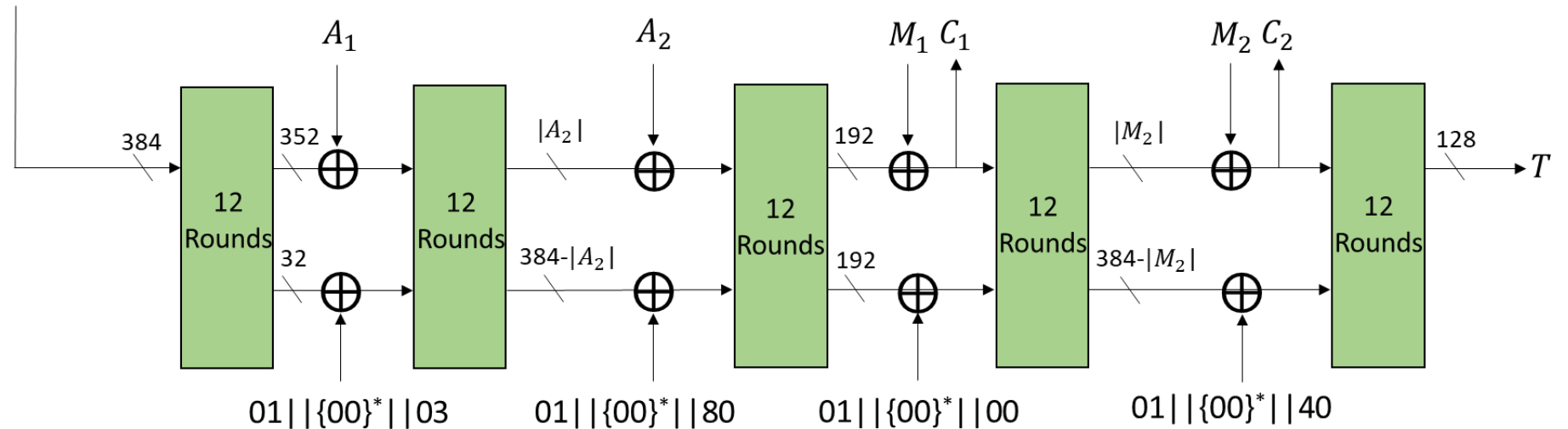


# XOODYAK

- Family of permutation based AEAD & hashing scheme
- Based on 384-bit Xoodoo permutation
- Uses Cyclist mode
- Design tweak: simplified initialization to improve performance for short messages

	Variant	Parameter sizes
AEAD	Xoodyak	128-bit key/nonce/tag
Hash	Xoodyak	256-bit digest
XOF	Xoodyak	Arbitrary length digest

$K || N || (\text{byte-length of } N) || 01 || \{00\}^* || 02$



# Underlying Components and Functionalities

## AEAD-only

### Permutation

Elephant

ISAP

### Block Cipher

GIFT-COFB

TinyJAMBU

### Stream cipher

Grain-128AEAD

## AEAD and Hashing

### Permutation

ASCON

PHOTON-Beetle

SPARKLE

Xoodyak

### Tweakable block cipher

Romulus

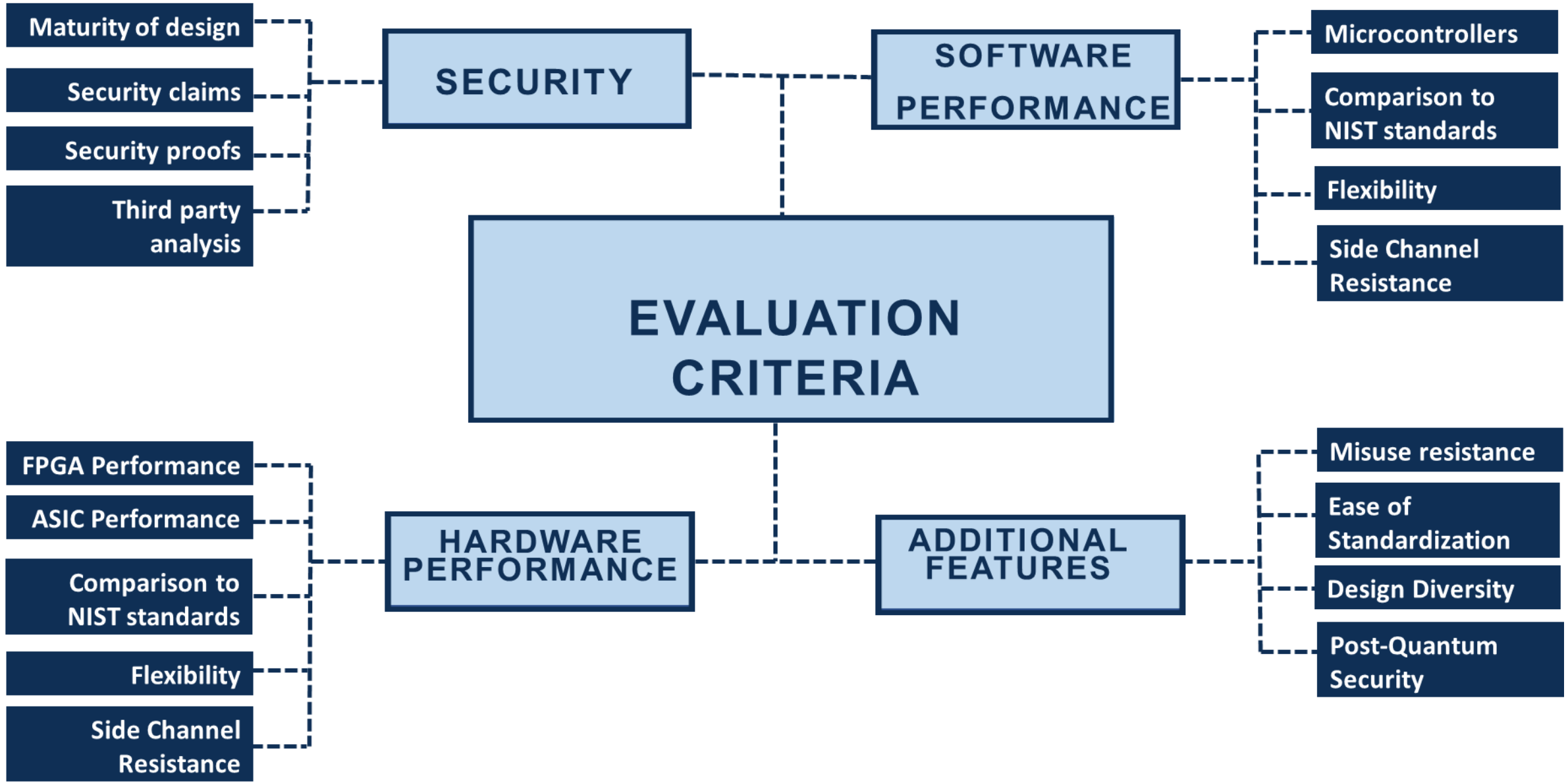
# Variants of the Finalists

Finalist	# Variants	Key size (bits)	Nonce size (bits)	Tag size (bits)	Digest size (bits)
Ascon	3 AEAD	128 - 160	128	128	--
	2 hash	--	--	--	256
Elephant	3 AEAD	128	96	64-128	--
GIFT-COFB	1 AEAD	128	128	128	--
Grain-128aead	1 AEAD	128	96	64	--
ISAP	4 AEAD	128	128	128	--
PHOTON-Beetle	2 AEAD	128	128	128	--
	1 hash	--	--	--	256
Romulus	3 AEAD	128	128	128	--
	1 hash	--	--	--	256
Sparkle	4 AEAD	128-256	128-256	128-256	--
	2 hash	--	--	--	256-384
TinyJambu	3 AEAD	128-256	96	64	--
Xoodyak	1 AEAD	128	128	128	--
	1 hash	--	--	--	256

# Part III – Evaluation and Selection

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# Security Requirements

The submission call included the security requirements:

- Key size is at least 128-bit.
- The limits on the input sizes (e.g., message, AD) is at least  $2^{50}-1$  bytes.
- Any nonce-respecting attack on the AEAD with 128-bit key requires at least  $2^{112}$  time complexity on a classical computer in the single-key setting.  
(For 256 bit key, time complexity of at least  $2^{224}$ , if applicable.)
- Any attack on the hash function variants requires at least  $2^{112}$  time complexity on a classical computer (if applicable).

# Security Margins and Claims and Maturity

- All finalists have met the security requirements and provided sufficient security margins.
- None of the security claims made by the submitters have been invalidated.
- Maturity of the design is one of the important security evaluation factors.
  - Is the finalist based on well-established design principles?
  - Did the finalist receive enough third-party analysis?
  - Are there design tweaks that invalidate the earlier security analysis?
  - Are there any additional concerns (e.g., nonce misuse, related-key, RUP security, post quantum)?

# Security Evaluations of the Finalists

**Ascon:** Received large number of third-party analysis. High security margin. Best key-recovery attack on 7 (out of 12) rounds of initialization. Distinguishers on full permutation.

**Elephant:** High security margin. Best distinguisher\* on 160-bit Spongent permutation covers 40 (out of 80) rounds. Some results on Even-Mansour construction in the quantum setting.

**GIFT-COFB:** Large number of third-party analysis on GIFT. Best key-recovery attack on GIFT-128 covers 27 (out of 40) rounds. High security margin. Some level of nonce-misuse resilience.

**Grain-128AEAD:** Large number of third-party analysis on *earlier* versions. Tweaked in response to the state-recovery observation. Best key-recovery attack\* covers 192 (out of 512) rounds of initialization. High security margin.

**ISAP:** Large number of third-party analysis on Ascon permutation. Best forgery attack covers 4 (out of 12) rounds. High security margin.

\*Requires time complexity beyond the time limit made by the submitters.

# Security Evaluations of the Finalists

**Photon-Beetle:** No analysis on round-reduced Photon-Beetle-AEAD. Distinguishing attack on the permutation covers 10 (out of 12) rounds.

**Romulus:** High security margin. Number of rounds reduced from 56 to 40. Best key-recovery attacks\* on Skinny with 32 (out of 40) rounds in the related-key setting. Nonce misuse resistance. For hash variant, preimage attack\* on 23 (out of 40) rounds.

**Sparkle:** High security margin. Best key-recovery attack\* covers 4.5 (out of 11) steps of 384-bit permutation without whitening. No known results on the hash variants. Distinguishers\* on permutation up to 6 steps.

**TinyJambu:** Tweak to increase the number of rounds. Weak-key distinguishing attack covers 476 (out of 1024) rounds. Forgery attacks on full-round TinyJambu-192 and TinyJambu-256 in the related-key setting.

**Xoodyak:** Best key recovery attack covers 6 (out of 12) rounds. High security margin.

\*Requires time complexity beyond the time limit made by the submitters.



# Software Benchmarking

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# Software Benchmarking

## Microcontroller benchmarking by NIST LWC Team

### Devices:

- 8-bit AVR
- 32-bit ARM Cortex M0+, M4, M3
- MIPS32 M4K
- Tensilica L106

### Metrics:

- Code size
- Execution time

## Microcontroller benchmarking by Renner et al.

### Devices:

- 8-bit AVR
- 32-bit ARM Cortex M3, M7
- Tensilica Xtensa LX6
- RISC-V

### Metrics:

- Speed
- Code Size
- RAM usage

## Microcontroller benchmarking by Weatherly

### Devices:

- AVR
- ARM Cortex-M3
- Tensilica Xtensa LX6

### Metrics:

- Speed

## eBACS (ECRYPT Benchmarking of Cryptographic Systems) by Lange and Bernstein

### Devices:

- Many systems covering ARM, AMD, Intel, PPC, RISC V, and MIPS architectures

### Metrics:

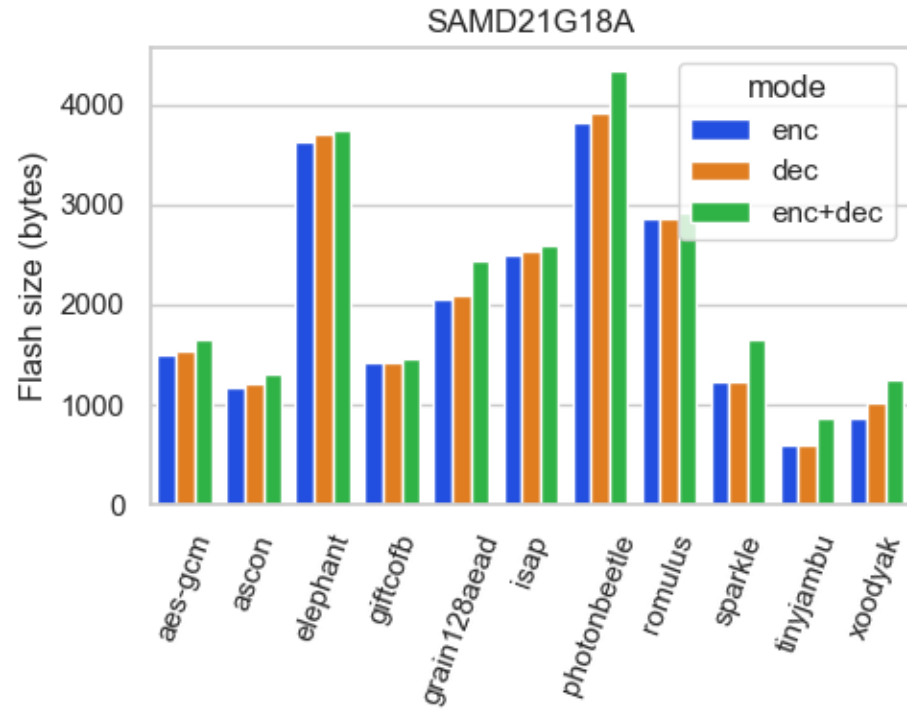
- Speed



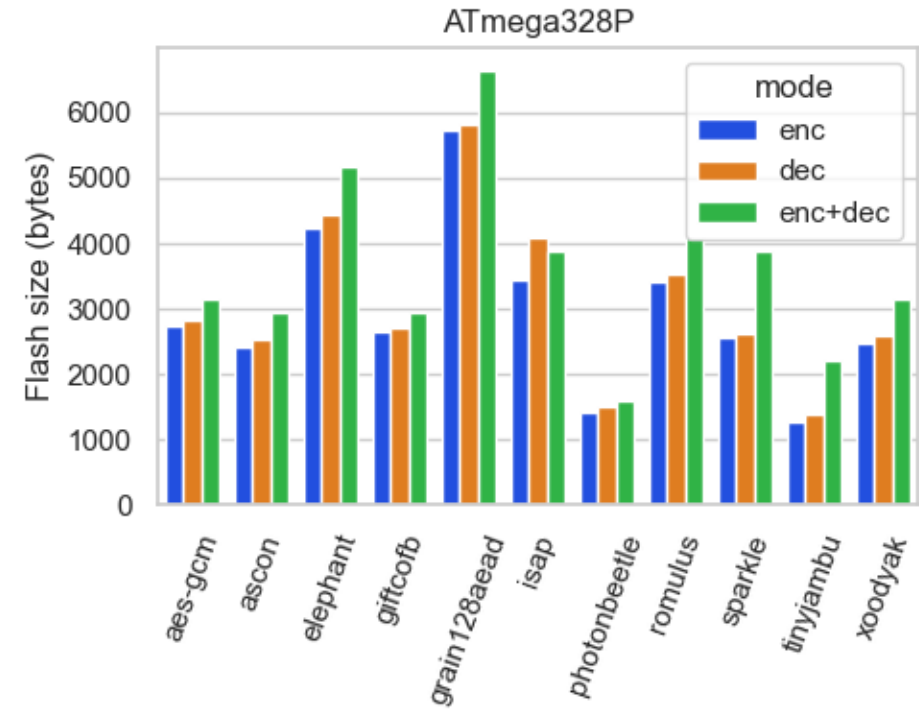
# Available Implementations

Finalist	#AEAD	#Hash	#Combined	Total
Ascon	120	110	52	282
Elephant	6	-	-	6
GIFT-COFB	11	-	-	11
Grain-128AEAD	6	-	-	6
ISAP	37	1	4	42
PHOTON-Beetle	20	10	16	46
Romulus	32	11	27	70
Sparkle	25	13	3	41
TinyJambu	9	-	-	9
Xoodyak	9	8	1	18
<b>Total</b>	<b>275</b>	<b>153</b>	<b>103</b>	<b>531</b>

# Size comparisons

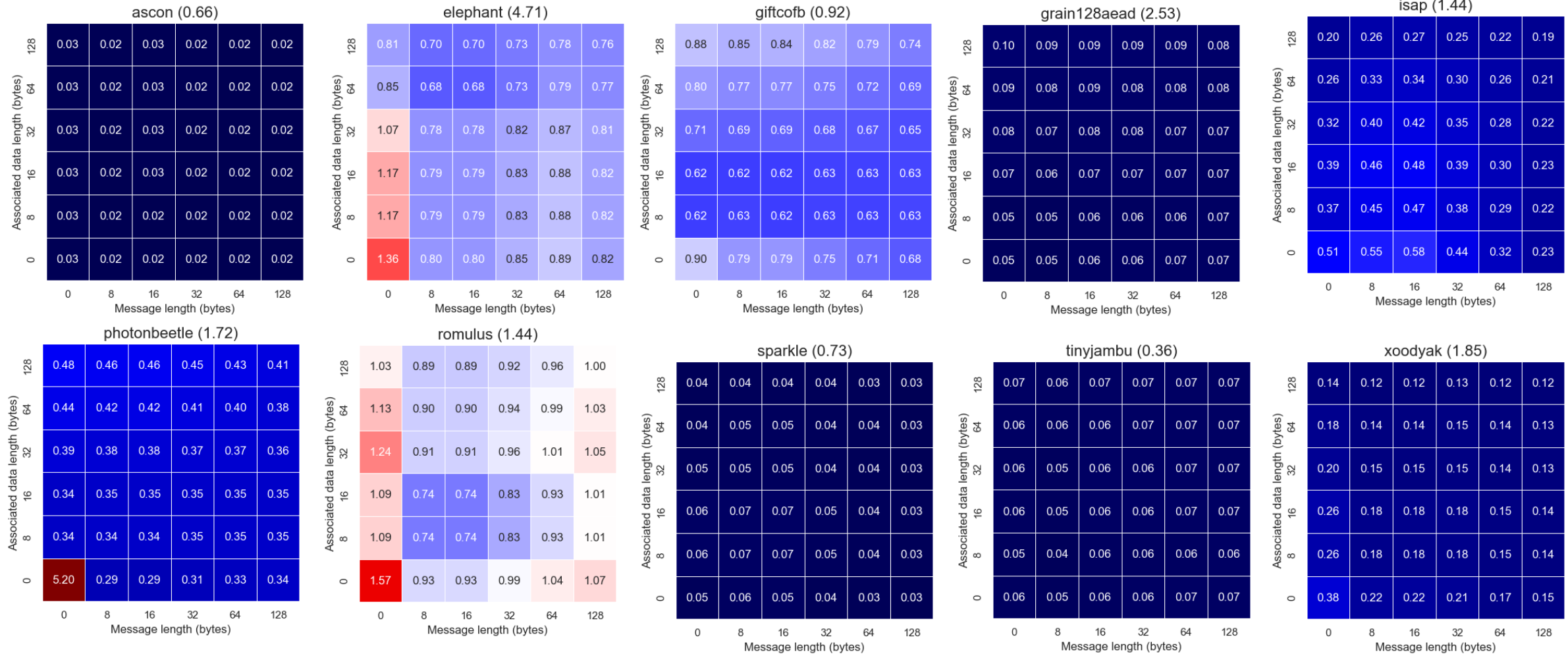


32-bit ARM Cortex-M0+



8-bit AVR

# Execution time comparison to AES



Execution time ratio of smallest primary AEAD implementations to AES-GCM on nRF52840

# Summary of Results

A group of candidates emerged as having compact and fast implementations across software platforms and studies (listed alphabetically)

<b>AEAD</b>	<b>Hashing</b>	<b>AEAD + hashing</b>
Ascon	Ascon	Ascon
GIFT-COFB	SPARKLE	SPARKLE
SPARKLE	Xoodyak	Xoodyak
TinyJAMBU		
Xoodyak		

# Hardware Benchmarking

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# Hardware Benchmarking (Round 2)

Top performers across hardware technologies and studies (listed alphabetically)

<i>Initiative</i>	<i>Platforms</i>	<i>Metrics</i>
GMU CERG group [270]	Xilinx Artix-7 Intel Cyclone 10 LP Lattice Semiconductor ECP5	Resource utilization (LUT or LE, flip-flops) Maximum clock frequency (MHz) Throughput (Mbits/s) Energy per bit (nJ/bit)
Khairallah et al. [274]	TSMC 65nm FDSOI 28nm	Area ( $\mu m^2$ and GE) Clock period (ns) Power (mW) Energy (mJ)
Aagaard and Zidarič [276]	ST Micro 65nm TSMC 65nm ST Micro 90nm TSMC 90nm ARM/IBM 130nm	Throughput (bits per cycle) Area (GE) Energy (nJ) Area×Energy (GE×nJ) Clock Speed (GHz)

<b>Area</b>	<b>Energy</b>	<b>Throughput</b>
Ascon	Ascon	Ascon
GIFT-COFB	GIFT-COFB	GIFT-COFB
Romulus	TinyJAMBU	TinyJAMBU
TinyJAMBU	Xoodyak	Xoodyak

Anticipated effects of final round tweaks:

- Romulus and Xoodyak: tweaked to increase performance.  
Decrease energy, increase throughput.
- TinyJambu tweaked to increase security  
Increase energy, decrease throughput



# Protected Implementations

**NIST**

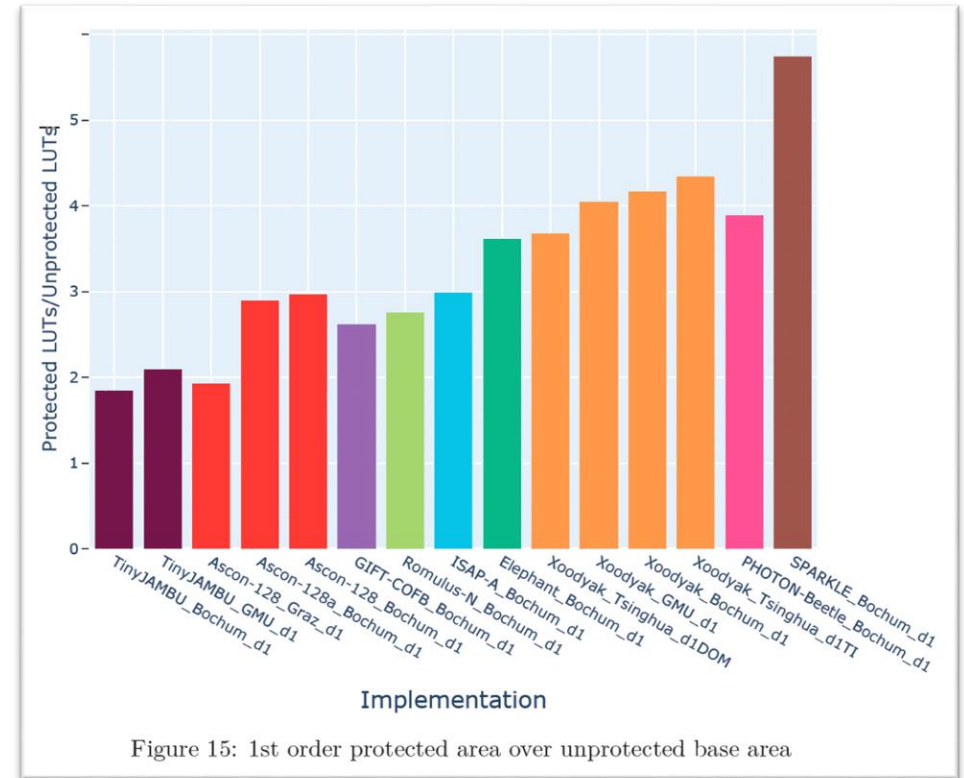
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# Protected Implementations

In January 2022, GMU organized effort to evaluate protected hardware and software implementations and published three calls:

- Call for Protected Hardware Implementations
- Call for Protected Software Implementations
- Call for Side-Channel Security Evaluation Labs

Benchmarked implementations with 1<sup>st</sup>, 2<sup>nd</sup>, and 3<sup>rd</sup> order masking.



TinyJAMBU, Ascon, and GIFT-COFB had lowest first-order protected area over base area.

# Part IV – Selection and Next Steps

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# Selection Process

Fair evaluation of finalists is challenging

- Assigning different weights for different criteria (security, performance in software and hardware, design maturity, amount of third-party analysis, IP issues, etc.)
- Different security claims, different functionality, attacks with different complexities etc.
- Limited resources (not all algorithms got the same attention from the crypto community) for security analysis and benchmarking.

Decision relied on publicly available analysis and benchmarking results.

# Selection of Ascon

In February 2023, NIST announced the Ascon family as the winner.

- High security margin, large number of third-party analysis
- No design tweaks
- Primary choice for the for lightweight applications in the final CAESAR portfolio
- Mode-level protection mechanism for security against leakage.
- Support for additional functionalities XOF, dedicated MAC, in addition to Hash
- Performs better than the NIST standards in hardware and software benchmarks
- Implementation and design flexibility
- Lower additional cost for protected implementations



# Which variants?

	Variant	Parameter sizes
AEAD	<b>Ascon-128</b>	128-bit key/nonce/tag
	Ascon-128a	128-bit key/nonce/tag
	Ascon-80pq	160-bit key, 128-bit nonce/tag

	Variant	Parameter sizes
Hash	<b>Ascon-Hash</b>	256-bit digest
	Ascon-Hasha	256-bit digest
XOF	Ascon-XOF	Arbitrary length digest
	Ascon-XOFa	Arbitrary length digest

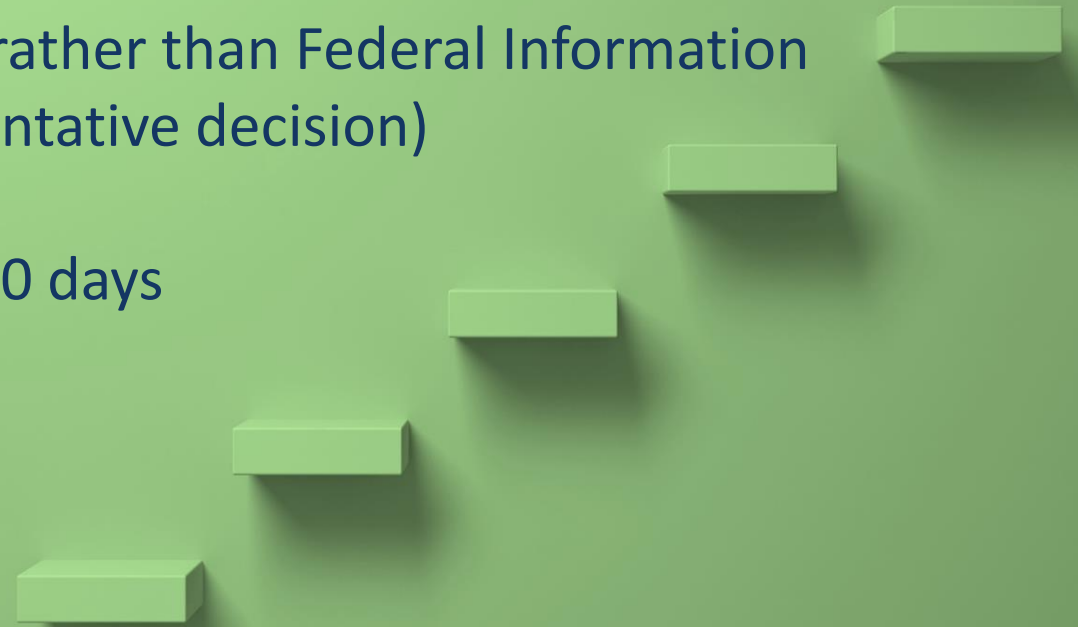
## Tentative decisions:

- Either Ascon-128 or both Ascon-128 and Ascon-128a
- Do not include Ascon-80pq
- XOF functionality instead of hash functions



# NEXT STEPS

- Publication of the draft standards describing the Ascon family (later in 2023)
  - Special Publication (SP) series rather than Federal Information Processing Standards (FIPS) (tentative decision)
- Public comments period of 60 to 90 days



# CONTACT US

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**PUBLIC FORUM** [lwc-forum@list.nist.gov](mailto:lwc-forum@list.nist.gov)

**GITHUB** <https://github.com/usnistgov/Lightweight-Cryptography-Benchmarking>

**WEBSITE** <https://csrc.nist.gov/Projects/lightweight-cryptography>