APE: Authenticated Permutation-Based Encryption for Lightweight Cryptography

Elena Andreeva, Begül Bilgin, Andrey Bogdanov, Atul Luykx, Bart Mennink, Nicky Mouha, Kan Yasuda

KU Leuven, UTwente, DTU, NTT

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Authenticated Encryption

- Privacy
- Authenticity

Authenticated Encryption for Lightweight Cryptography

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Lightweight

- Constrained environments
- Online
- Nonce-reuse

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Primitive

- Block cipher
- Permutation

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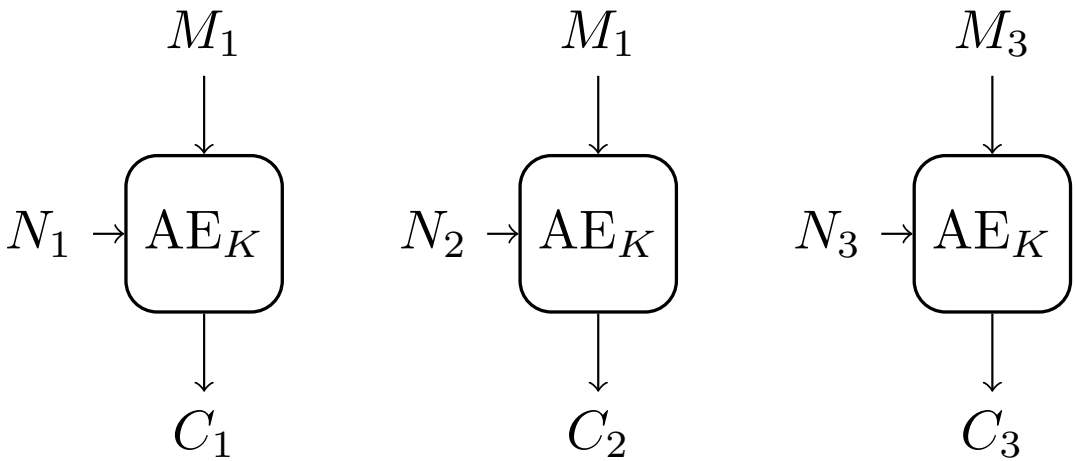
Primitive

- Block cipher ✗
- Permutation ✓

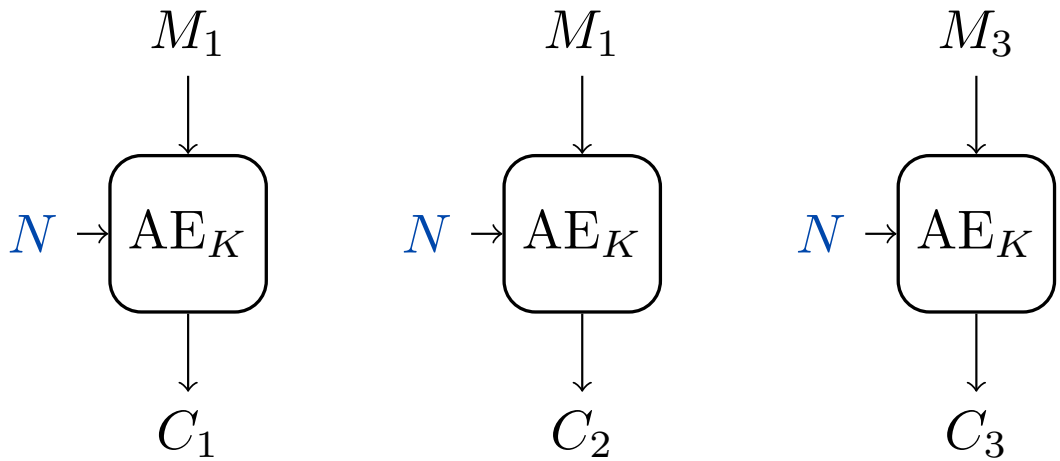
Misuse Resistance



Nonce

- Counter or random number
- Requires non-volatile memory or hardware randomness

Misuse Resistance



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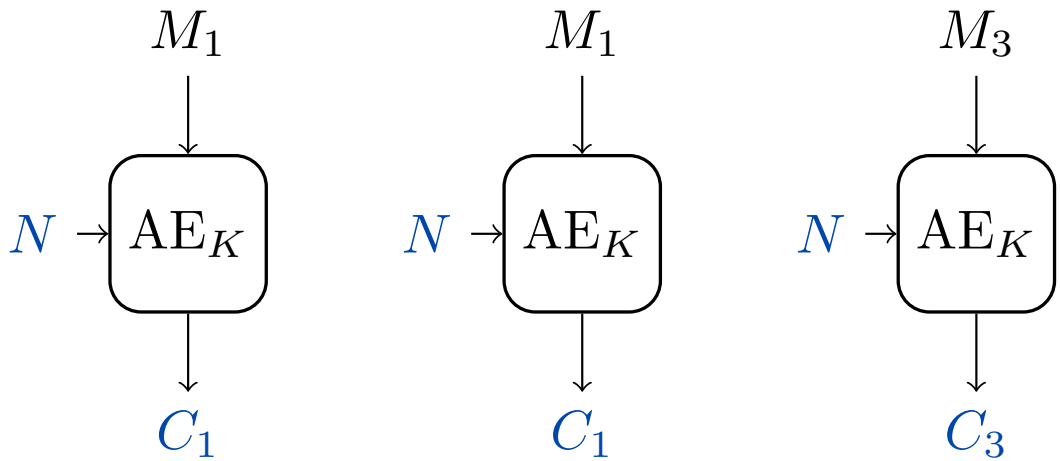

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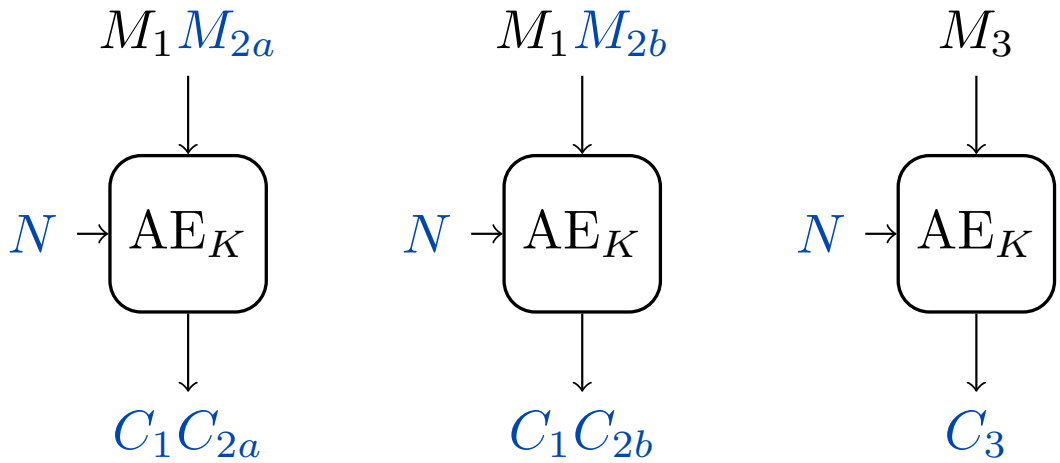

Nonce

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Misuse Resistance

- Online misuse resistance
- Security up to common prefix

State of the Art

	nonce-dependent	**misuse resistant**
block cipher	IAPM '00, OCB '01 XECB '01, CCM '03 GCM '04, CLOC '14	SIV '06, BTM '09 McOE-G '11, COPA '13 POET '14, COBRA '14
permutation	SpongeWrap '11 Keyak&Ketje '14 NORX '14	

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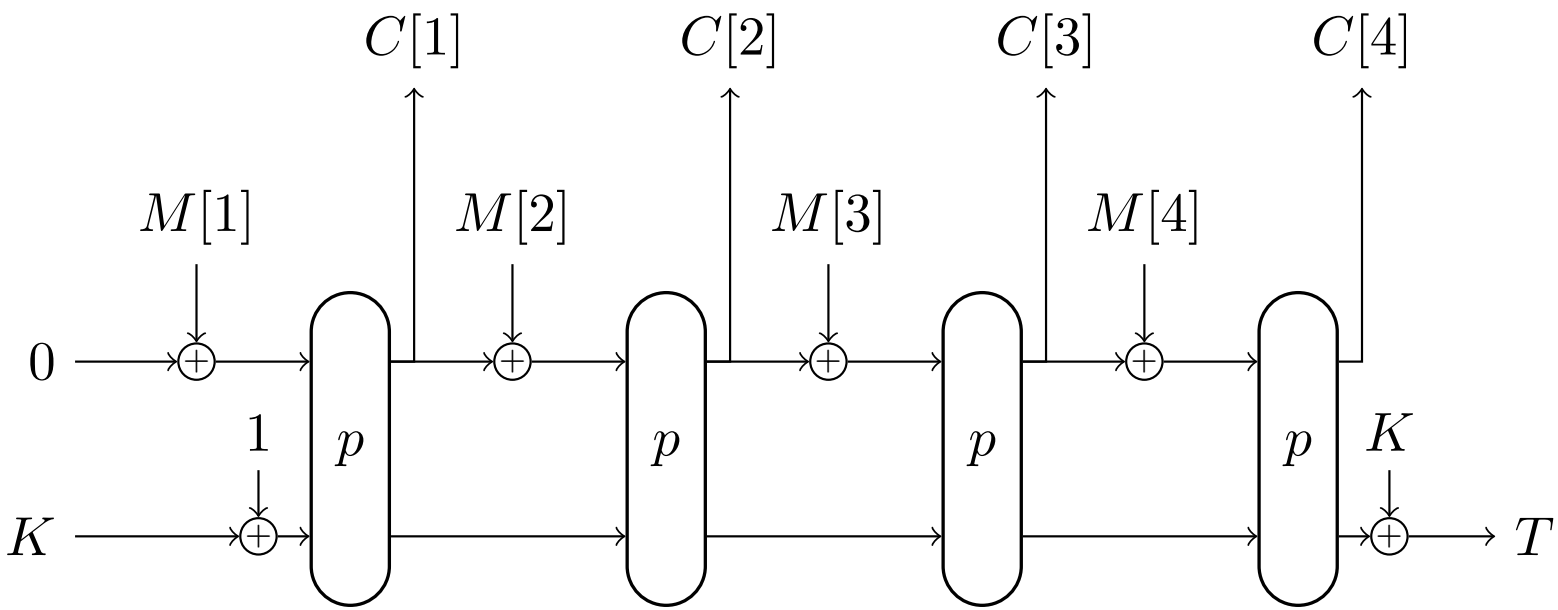
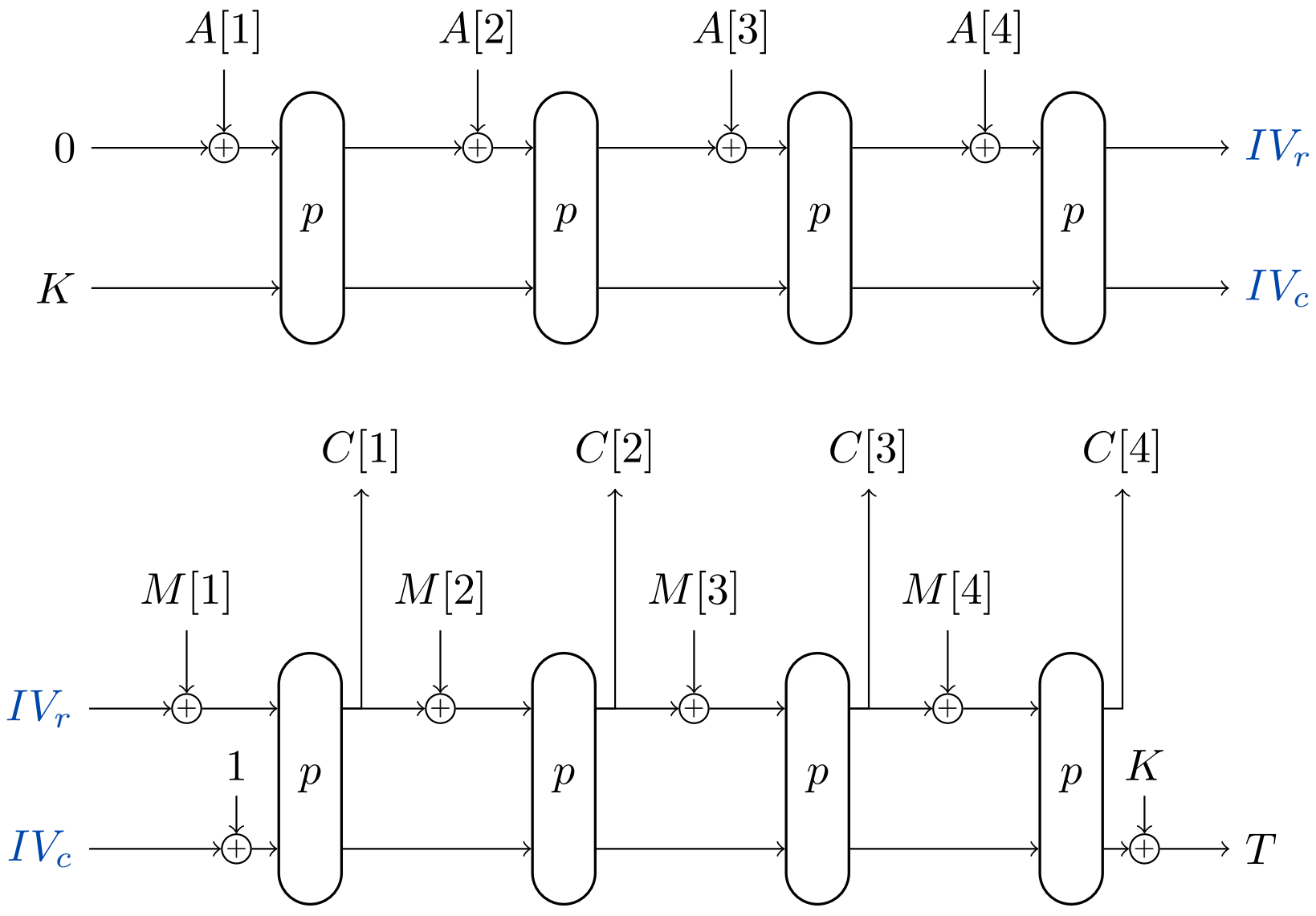
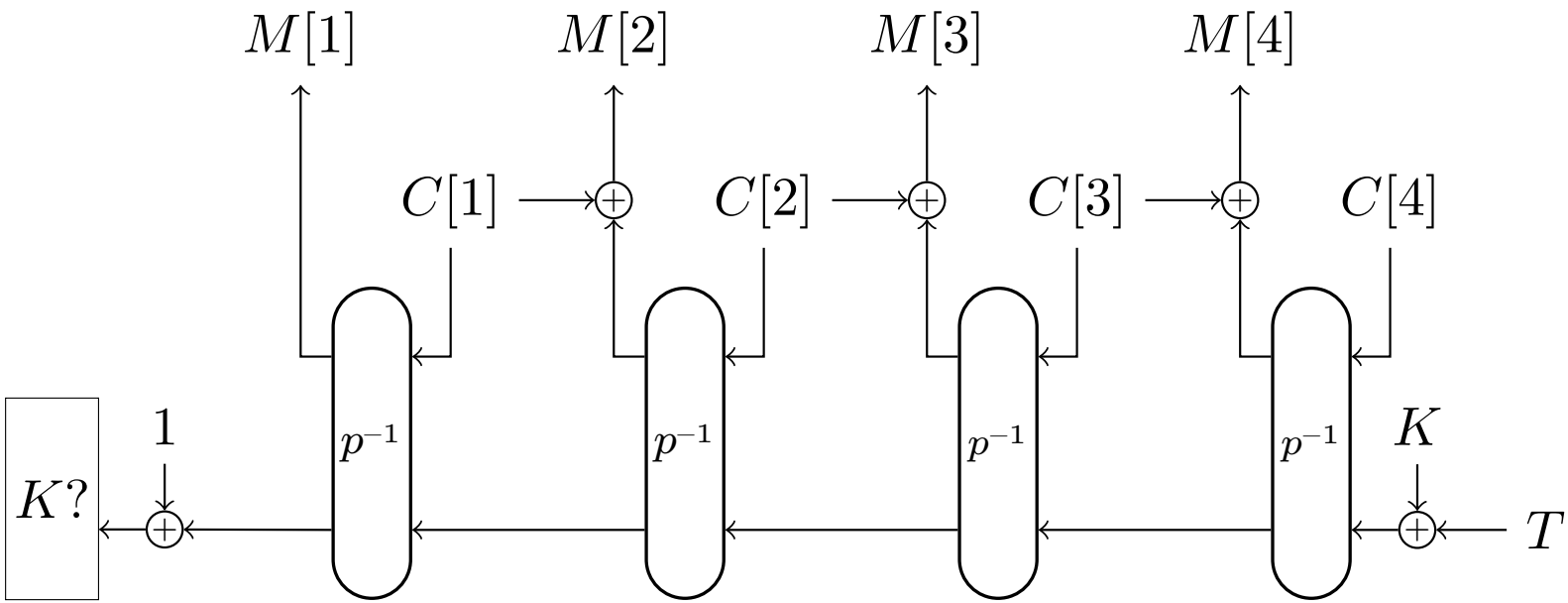


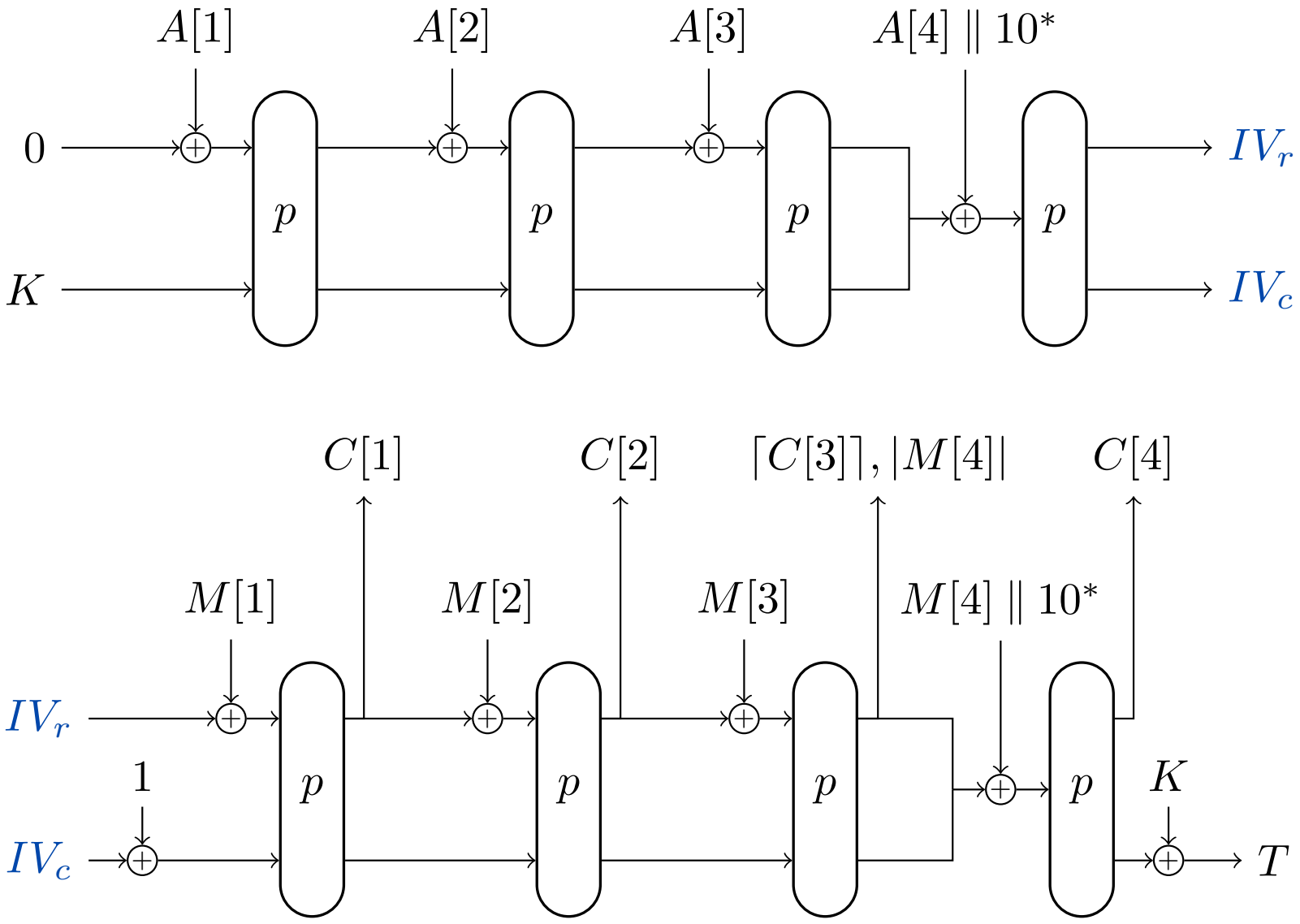
APE: Associated Data



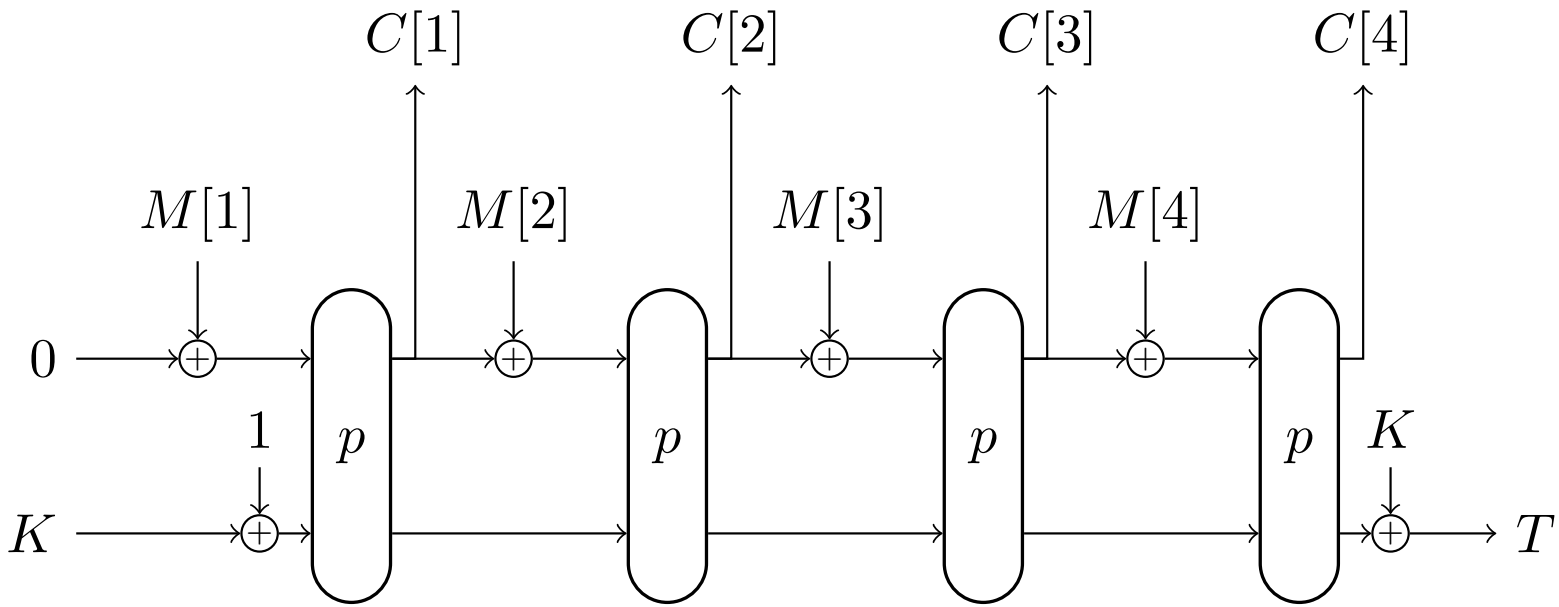
APE: Decryption and Verification



APE: Fractional Messages and Associated Data

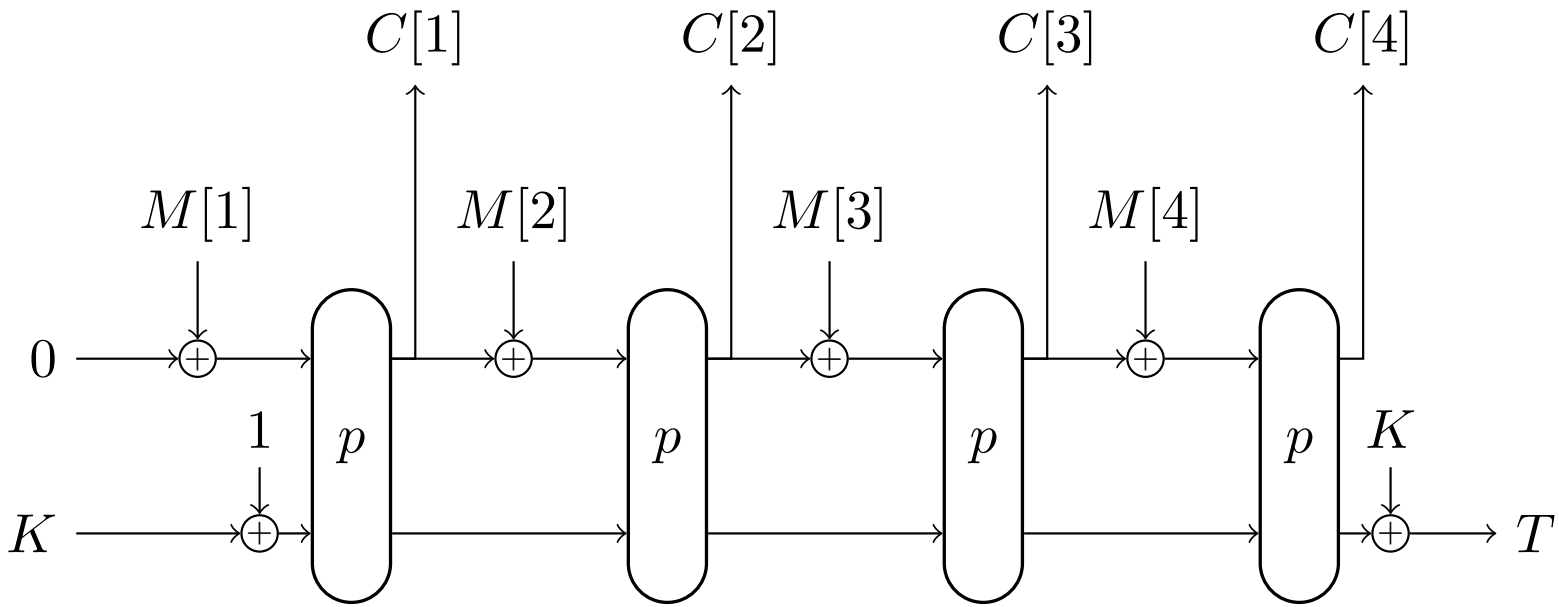


APE: Security



Ideal Permutation Model

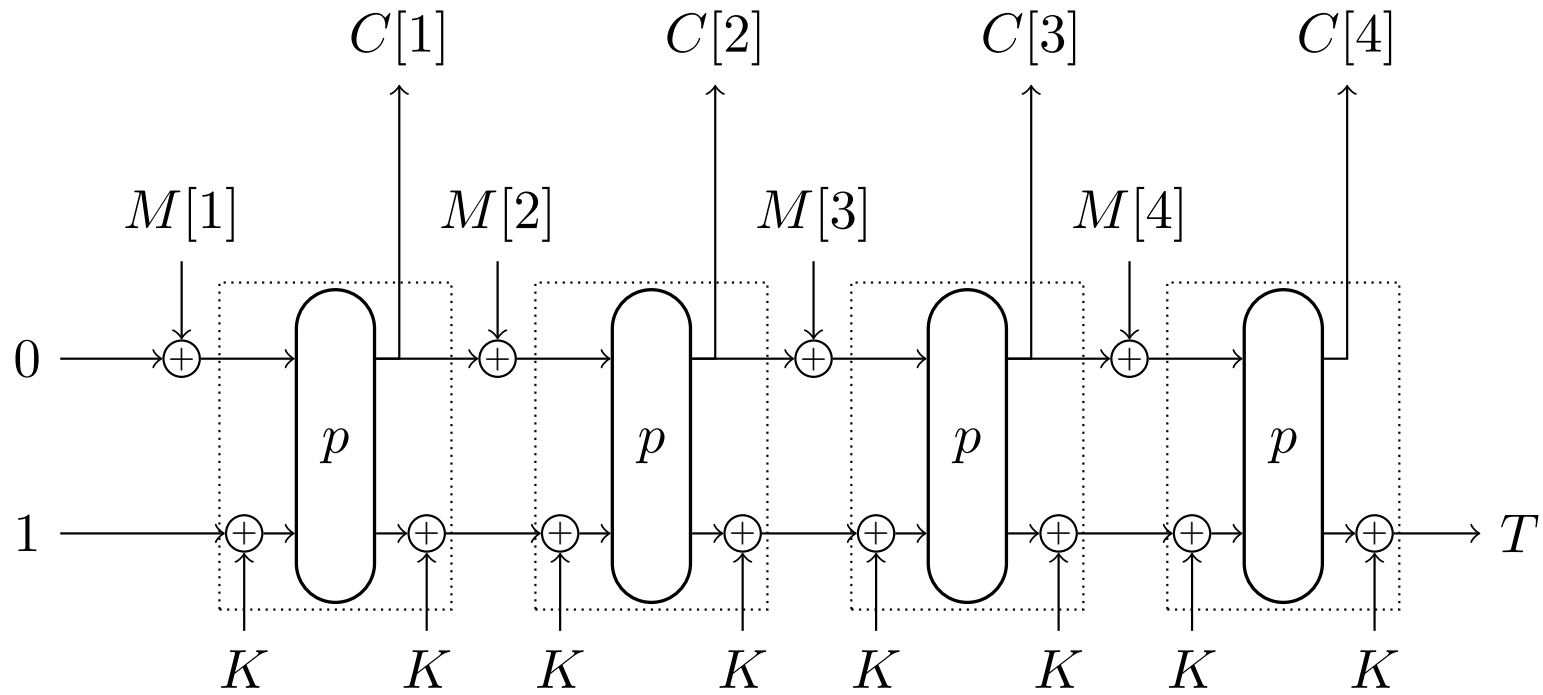
APE: Security



Ideal Permutation Model

- Privacy: $2^{c/2}$
- Integrity: $2^{c/2}$

APE: Security



Ideal Permutation Model

- Privacy: $2^{c/2}$
- Integrity: $2^{c/2}$

Standard Cipher Model

- $E := \oplus_{0\|K} \circ p \circ \oplus_{0\|K}$
- Privacy: $2^{c/2} + \mathsf{sprp}(E)$
- Integrity: $2^{c/2} + \mathsf{sprp}(E)$

APE: Hardware Implementation

Two platforms

- Faraday Standard Cell Library on UMC 180nm
- Open-cell 45nm NANGATE library

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Permutation

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- APE enc/dec

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Permutation

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Parameters

- Security: 80, 128 bits
- Rate: 16, 32 bits

APE: Implementation Results

APE enc/dec

- 1309 GE: smallest impl. with 80-bit security
- 2104 GE: smallest impl. with 128-bit security

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Decryption overhead

- Implement both p and p^{-1}
- 45nm: overhead $\leq$ 283 GE

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- Implement both p and p^{-1}
- 45nm: overhead $\leq$ 283 GE

Area comparison

- $\approx$ ALE
- $\ll$ ASC-1 A, ASC-1 B, AES-CCM

Conclusions

Features

- First permutation-based online misuse-resistant AE
- Easy processing of fractional data
- Ideal for lightweight
- Ideal model security proof
- Standard model security proof

Thank you for your attention!

Questions?

Supporting Slides

How to Securely Release Unverified Plaintext in Authenticated Encryption

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APE on UMC 180 nm

APE on UMC 180 nm CMOS process @ 100 kHz					
Design	Security (bits)	Rate (bits)	Latency (cycles)	Throughput (kbps)	Area (GE)
Photon-196	80	36	1248	2.9	1398
Photon-196 e/d	80	36	1297	2.8	1634
Quark-176	80	16	880	1.81	1694
Quark-176 e/d	80	16	880	1.81	1871
Spongent-176	80	16	4050	0.4	1423
Spongent-176 e/d	80	16	4094	0.4	1868
Photon-288	128	32	924	3.45	2154
Photon-288 e/d	128	32	960	3.33	2449
Quark-256	112	32	1270	2.51	2286
Quark-256 e/d	112	32	1270	2.51	2470
Spongent-272	128	16	4480	0.4	2105
Spongent-272 e/d	128	16	4652	0.3	2781

APE on NANGATE 45 nm

APE on NANGATE 45 nm CMOS process @ 100 kHz					
Design	Security (bits)	Rate (bits)	Latency (cycles)	Throughput (kbps)	Area (GE)
Photon-196	80	36	1248	2.9	1309
Photon-196 e/d	80	36	1297	2.8	1536
Quark-176	80	16	880	1.81	1606
Quark-176 e/d	80	16	880	1.81	1773
Spongent-176	80	16	4050	0.4	1598
Spongent-176 e/d	80	16	4094	0.4	1838
Photon-288	128	32	924	3.45	2104
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Quark-256	112	32	1270	2.51	2228
Quark-256 e/d	112	32	1270	2.51	2331
Spongent-272	128	16	4480	0.4	2378
Spongent-272 e/d	128	16	4652	0.3	2661

Other AE Schemes on ST 65 nm

Other AE schemes on ST 65 nm CMOS LP-HVT process @ 20 MHz

Design	Security (bits)	Latency (cycles)	Throughput (kbps)	Area (GE)
ALE	128	105	121.9	2579
ALE e/d	128	105	121.9	2700
ASC-1 A	128	370	34.59	4793
ASC-1 A e/d	128	370	34.59	4964
ASC-1 B	128	235	54.47	5517
ASC-1 B e/d	128	235	54.47	5632
AES-CCM	128	452	28.32	3472
AES-CCM e/d	128	452	28.32	3765