Categorization of Faulty Nonce Misuse Resistant Message Authentication

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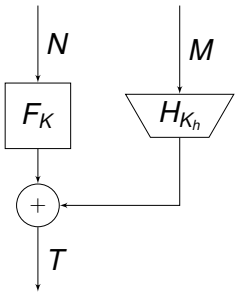
Digital Security Group, Radboud University

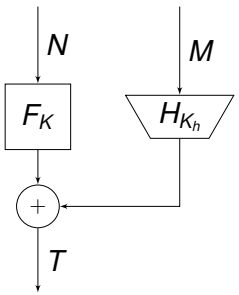
December, 2021

Nonce-Based MAC Algorithms and Wegman-Carter



Wegman and Carter (1981)

Nonce-Based MAC Algorithms and Wegman-Carter



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- Based on work of Gilbert, MacWilliams, and Sloane (1974)

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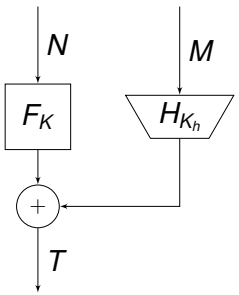

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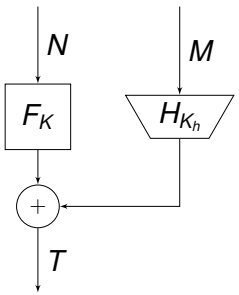

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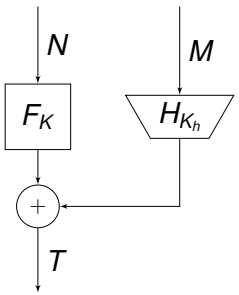

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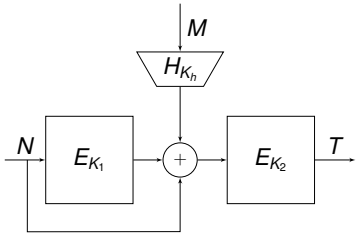
- Broken by nonce repetition

Encrypted Wegman-Carter with Davies-Meyer



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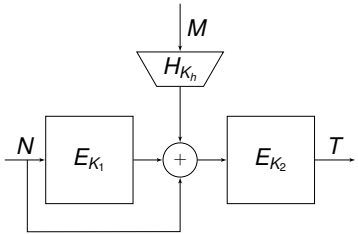

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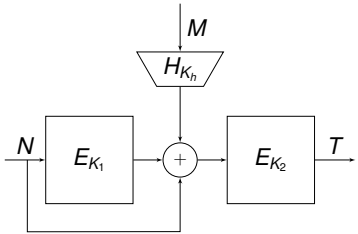

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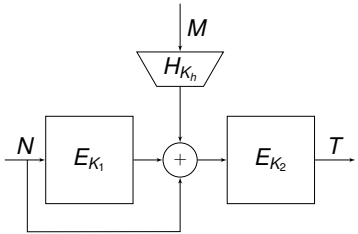

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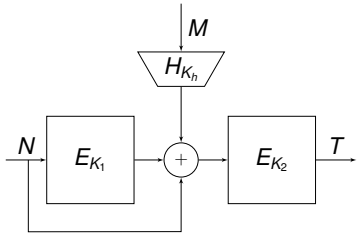

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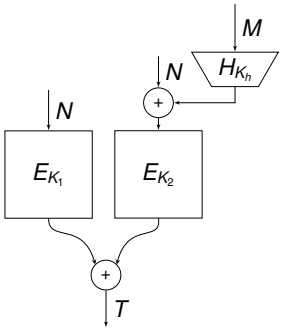
- Datta et al. (2018): DWCDM using one block cipher call with its inverse

Nonce-Based Enhanced Hash-then-Mask

Dutta et al. (2019)



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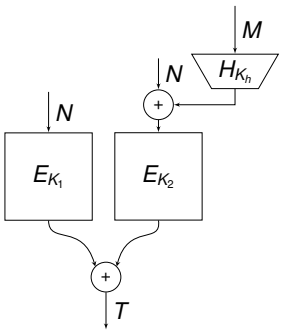

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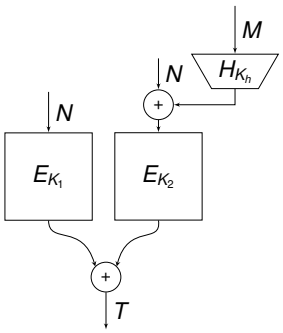

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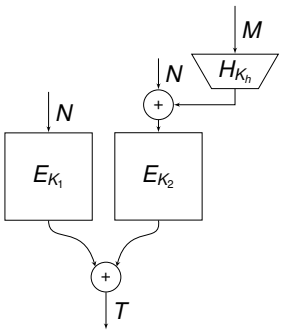

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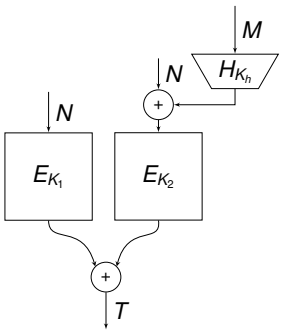

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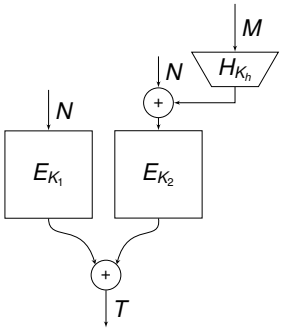

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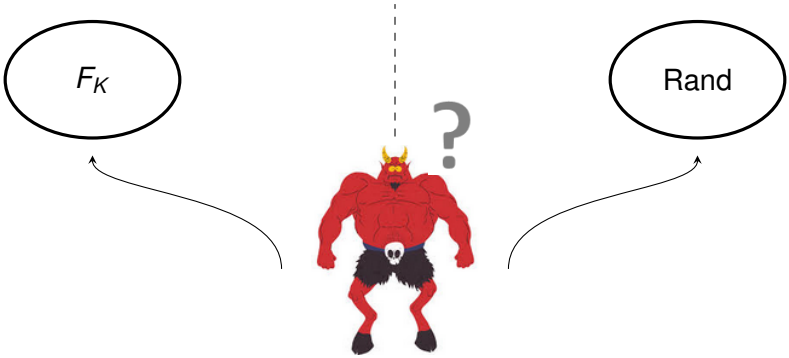
- Choi et al. (2020): $3n/4$-bit security if number of faulty queries $\leq 2^{3n/8}$

Security Definition



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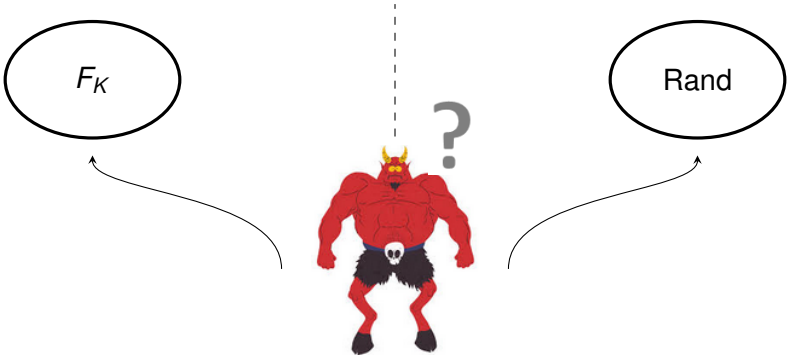
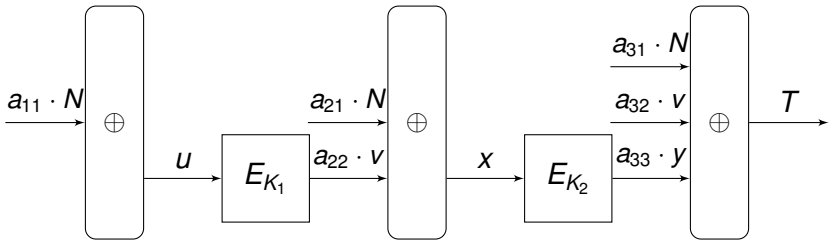


- Adversary $\mathcal{A}$ makes q queries to oracle (F_K or Rand)
- Good PRF $\iff$ $\mathcal{A}$ cannot determine which world it is interacting with

Generalized Fixed-Input-Length PRF Construction



- Fixed input-length PRFs from two block cipher calls

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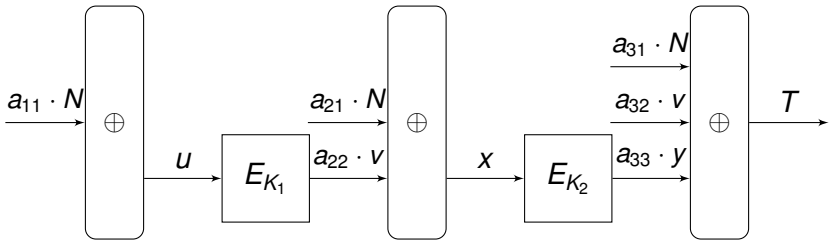

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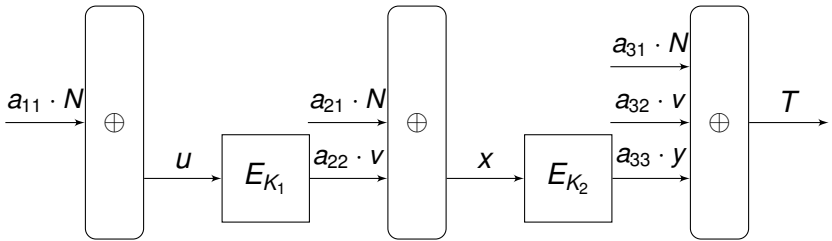

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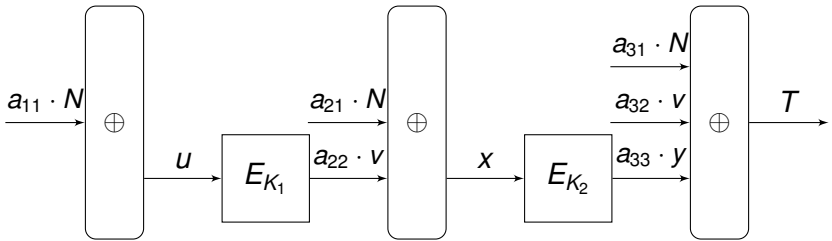

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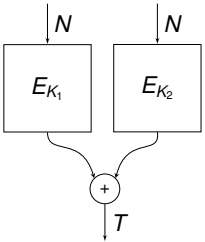
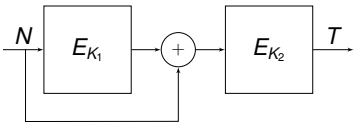
- We are only interested in beyond birthday bound secure PRFs

SoP, EDM, and EDMD



Sum of Permutations
(Bellare et al. 1998)



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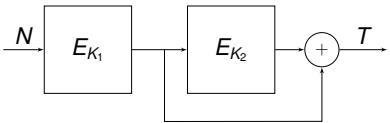

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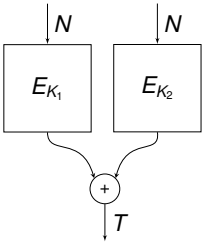

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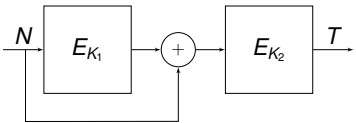

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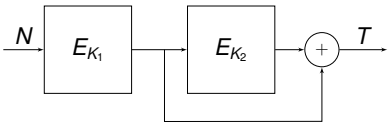

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n-bit security

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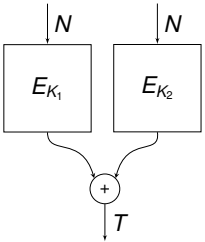

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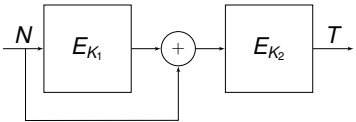

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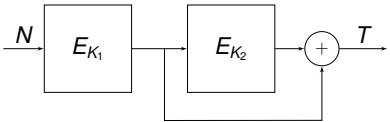

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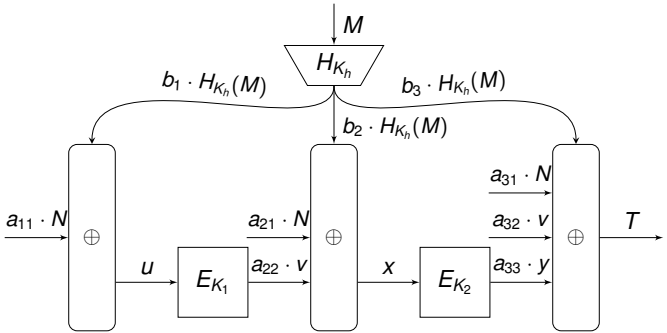
+ natural siblings of these 3 PRFs consist of XORing the input to the output

Generalized Nonce-Based MAC Algorithms



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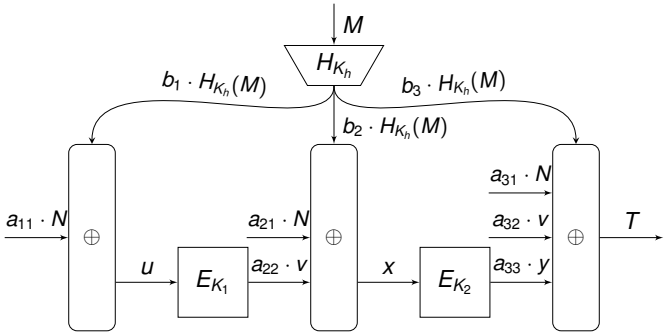

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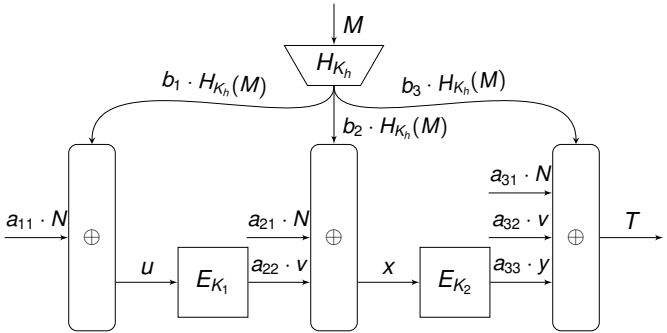

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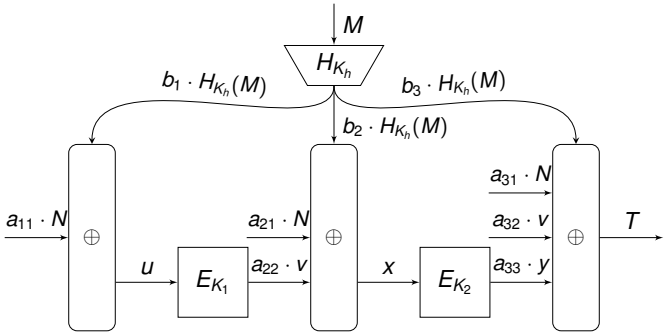

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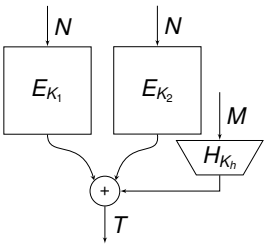
- In total 10 interesting constructions
  (5 based on EDM, 3 based on SoP, and 2 based on EDMD)

SoP, EDM, and EDMD Based Wegman-Carter



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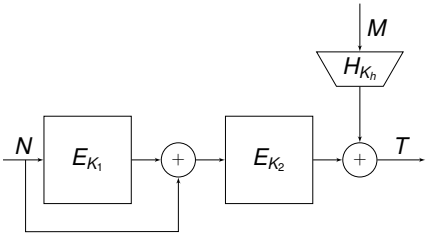
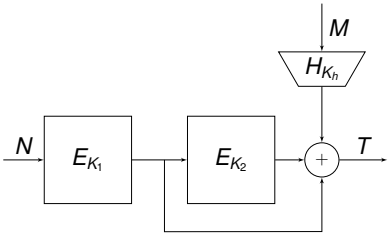


EDM Wegman-Carter



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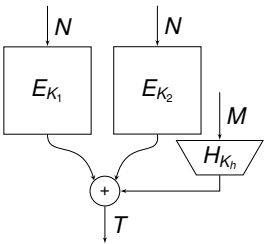

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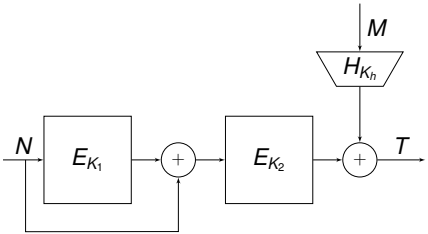

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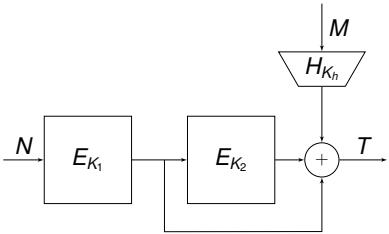

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n-bit security in nonce-respecting scenario

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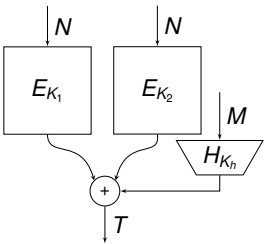

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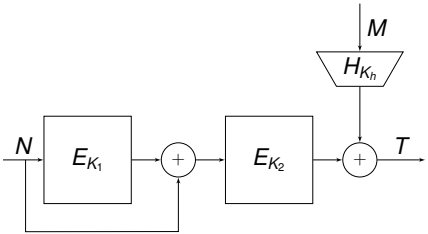

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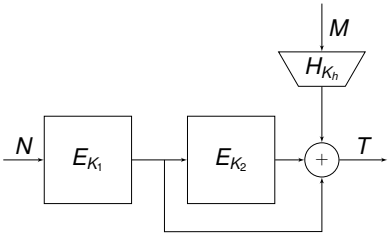
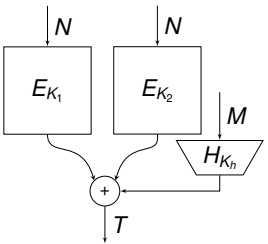


EDMD Wegman-Carter

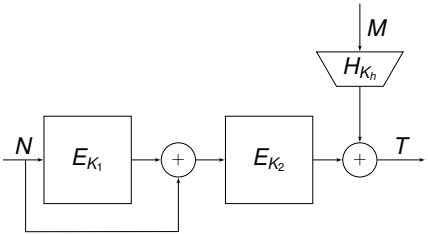
n-bit security in nonce-respecting scenario

Totally broken if a single nonce is re-used

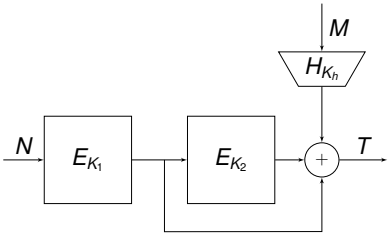
SoP, EDM, and EDMD Based Wegman-Carter



SoP Wegman-Carter



EDM Wegman-Carter



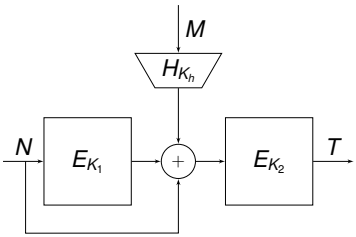
EDMD Wegman-Carter

n-bit security in nonce-respecting scenario

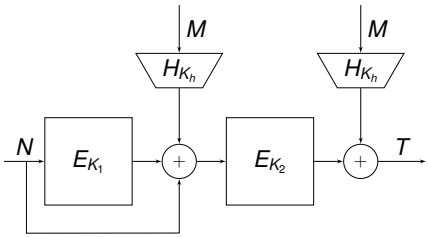
Totally broken if a single nonce is re-used

Schemes left: 4 based on EDM, 2 based on SoP, and 1 based on EDMD

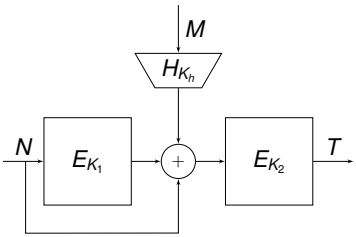
Nonce-Based MAC Algorithms Based on EDM (1)



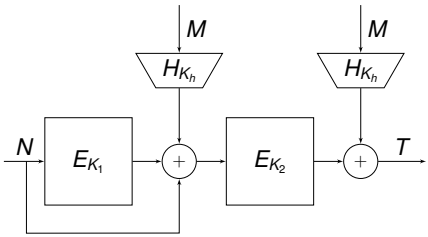
EWCDM



Nonce-Based MAC Algorithms Based on EDM (1)

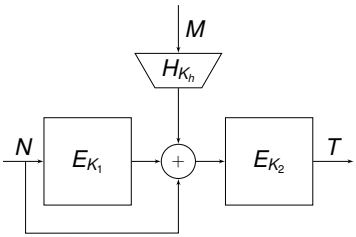


EWCDM

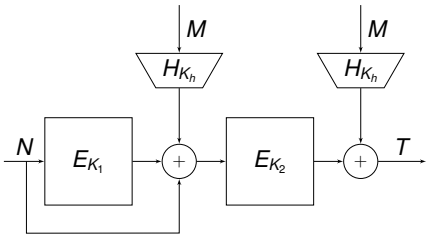


$3n/4$-bit security with concrete proof in nonce-respecting scenario

Nonce-Based MAC Algorithms Based on EDM (1)



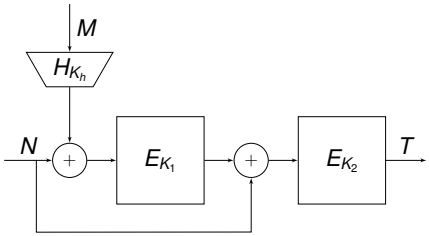
EWCDM

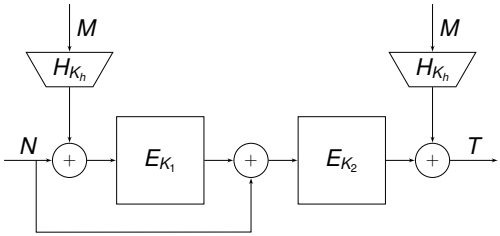


$3n/4$-bit security with concrete proof in nonce-respecting scenario

No graceful security degradation, $n/2$-bit security if a single nonce is re-used

Nonce-Based MAC Algorithms Based on EDM (2)





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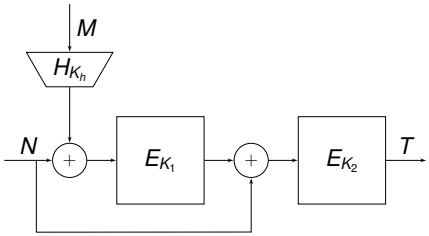
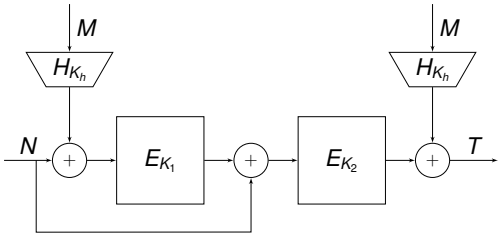
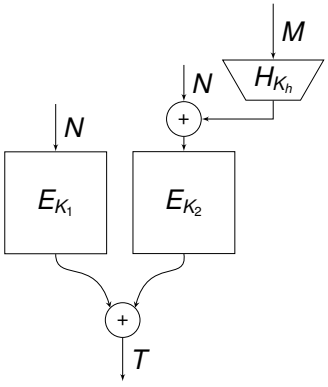


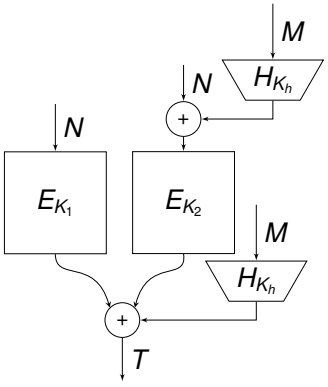


$3n/4$-bit security if number of faulty queries $\leq 2^{n/2}$

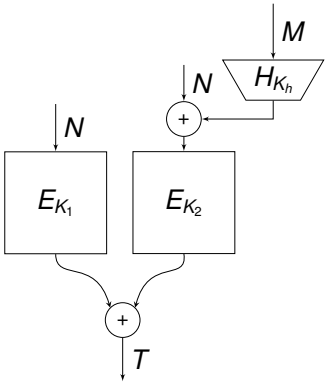
Nonce-Based MAC Algorithms Based on SoP



nEHtM



Nonce-Based MAC Algorithms Based on SoP



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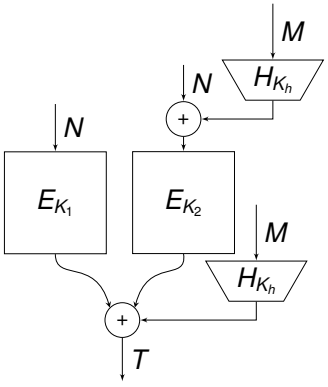
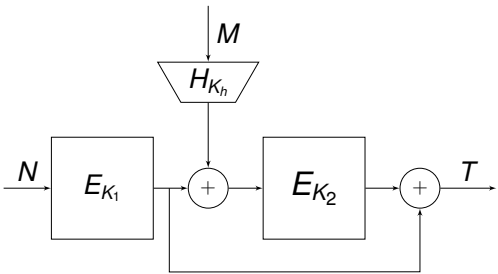
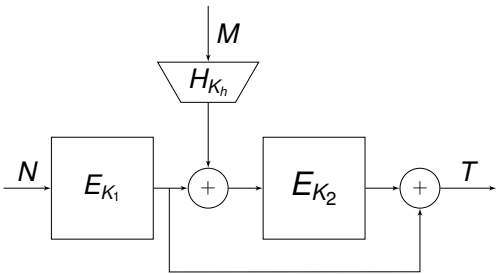


$3n/4$-bit security if number of faulty queries $\leq 2^{3n/8}$

Nonce-Based MAC Algorithm Based on EDMD



Nonce-Based MAC Algorithm Based on EDMD



- Outputs of E_{K_1} are not known

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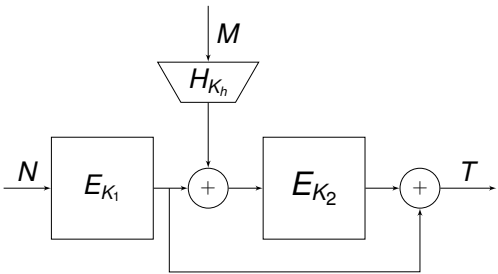

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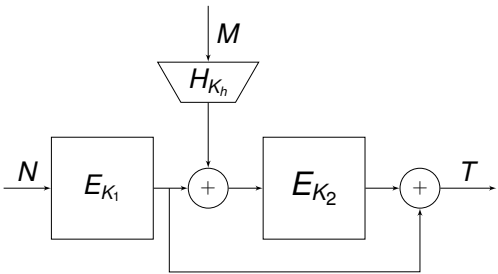

- Outputs of E_{K_1} are not known
- Outputs of E_{K_2} are also not known due to feed-forward (we only know T)
- Impossible to apply any other currently known technique

Security Analysis

- Patarin's H-coefficient technique

$$\frac{\Pr(X_{\mathcal{O}} = \tau)}{\Pr(X_{\mathcal{P}} = \tau)} \geq 1 - \epsilon$$

$$\mathbf{Adv}(\mathcal{A}) \leq \epsilon + \Pr(X_{\mathcal{P}} \in \mathcal{T}_{\text{bad}})$$

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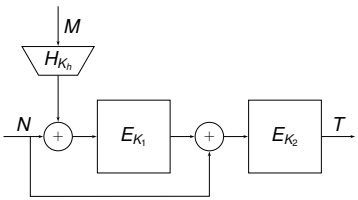
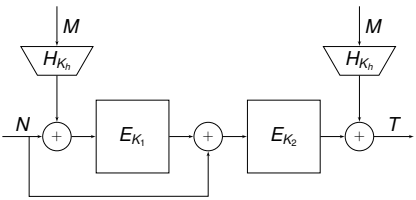
  - these two properties define $\Pr(X_{\mathcal{P}} \in \mathcal{T}_{\text{bad}})$

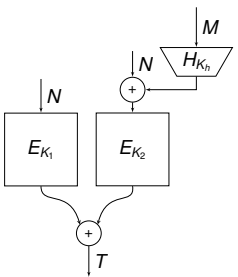
Comparison

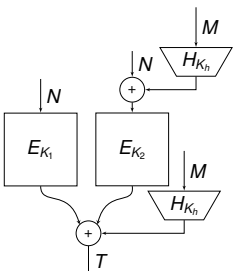
MAC	nonce-resp. security ($\log_2$)	nonce-misuse security ($\log_2$)	computing E_{K_1} without M	sequential/ parallel	security tightness	note
$F_{B_1}^{\mathrm{EDM}}$	n	0	✓	S	tight	WC-with-EDM
$F_{B_1}^{\mathrm{SoP}}$	n	0	✓	P	tight	WC-with-SoP
$F_{B_1}^{\mathrm{EDMD}}$	n	0	✓	S	tight	WC-with-EDMD
$F_{B_2}^{\mathrm{EDM}}$	$3n/4$ (n)	$n/2$	✓	S	not (tight)	EWCDM
$F_{B_3}^{\mathrm{EDM}}$	$3n/4$	$n/2$	✓	S	not	this work
$F_{B_4}^{\mathrm{EDM}}$	$3n/4$	$3n/4$ ($\mu < 2^{n/2}$)	—	S	?	this work
$F_{B_5}^{\mathrm{EDM}}$	$3n/4$	$3n/4$ ($\mu < 2^{n/2}$)	—	S	?	this work
$F_{B_2}^{\mathrm{SoP}}$	$3n/4$	$3n/4$ ($\mu \leq 2^{n/4}$)	✓	P	?	nEHtM
$F_{B_3}^{\mathrm{SoP}}$	$3n/4$	$3n/4$ ($\mu \leq 2^{n/4}$)	✓	P	?	this work
$F_{B_2}^{\mathrm{EDMD}}$	?	?	✓	S	—	—

Four MAC Algorithms with Graceful Security Degradation









Conclusion

New results

- All PRFs based on two block cipher calls
- All MAC algorithms based on one universal hash function and two block cipher calls
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Further research

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Thank you for your attention!