The Committing Security of MACs with Applications to Generic Composition

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Jérôme Govinden Yaobin Shen

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  - **Vulnerable settings:** moderation in encrypted messaging apps, key rotation mechanisms, password-based encryption, etc. [GLR17, DGRW18, LGR21, ADG+22]
  - **Vulnerable schemes:** AES-GCM, AES-GCM-SIV, ChaCha20-Poly1305, OCB3, CCM, EAX, SIV [LGR21, ADG+22, MLGR23]

→ Almost all standardized AEAD are vulnerable to committing attacks

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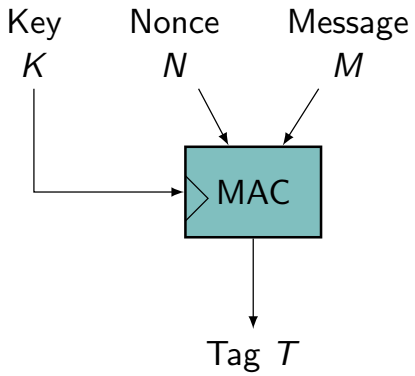

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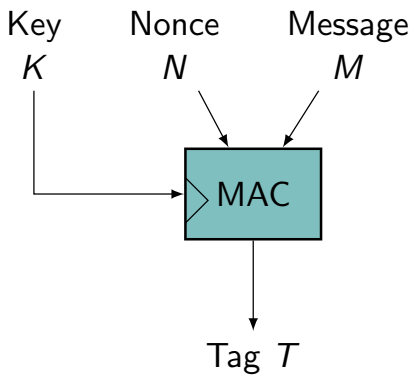

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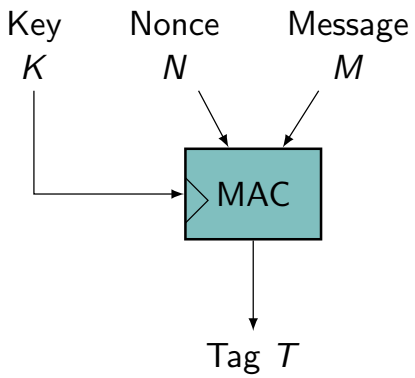

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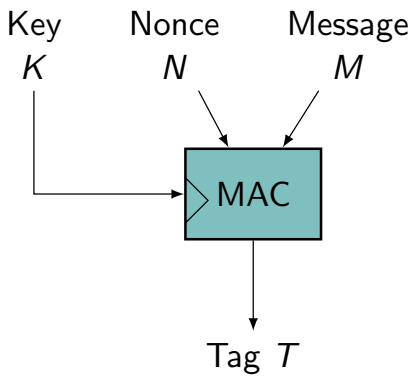

→ Committing security scarcely studied for MACs!

Settings Requiring Committing MACs

Practical Applications of Committing MACs

- We found four practical settings needing committing security:
  - The OPAQUE Augmented PAKE Protocol
  - Authentication without key identification
  - Collision Resistant KDF
  - Timed Efficient Stream Loss-Tolerant Authentication (TESLA)

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- Three of them implicitly assumed it to be guaranteed by their underlying MAC

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- CMAC is not context-committing

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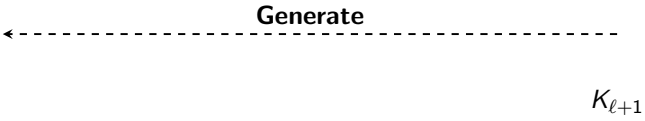

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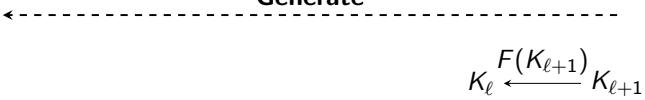

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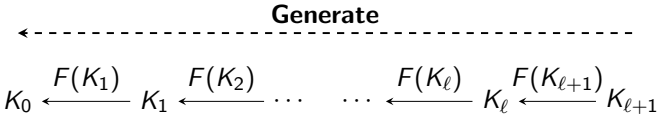

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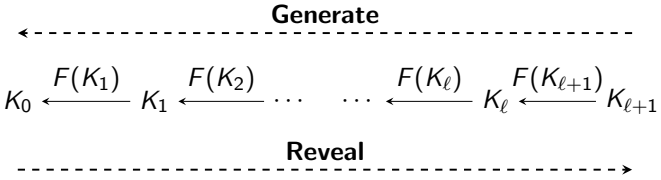

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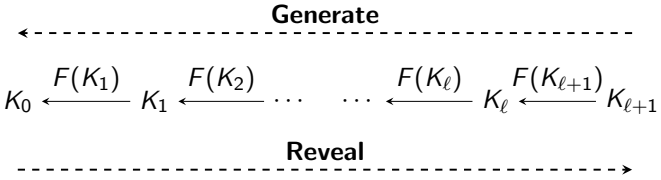

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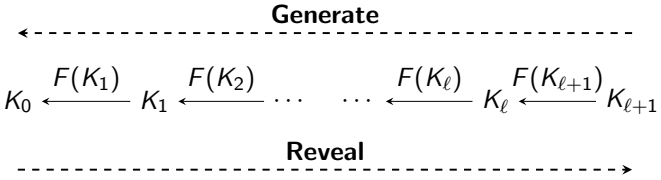

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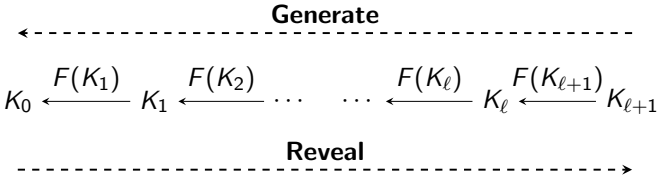

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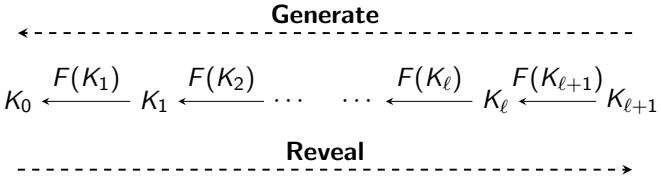

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Committing and CDY Security Notions for MACs

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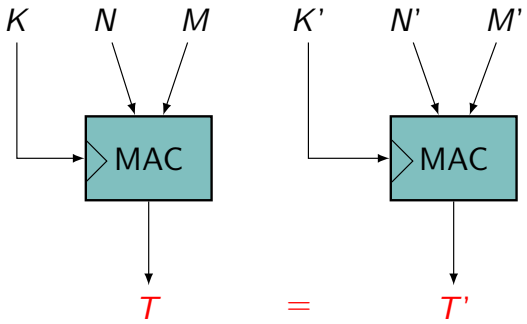

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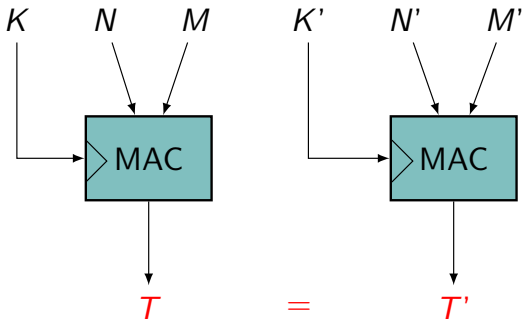

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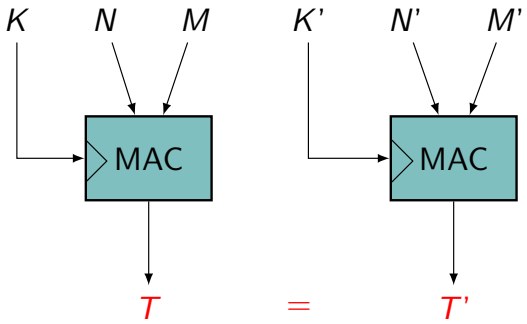

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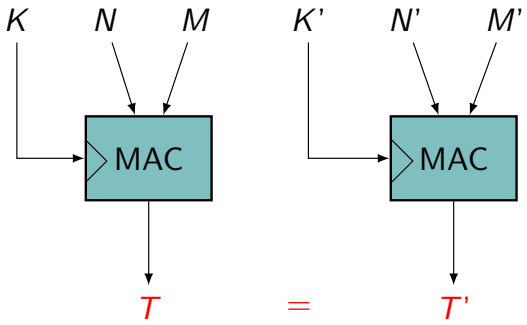

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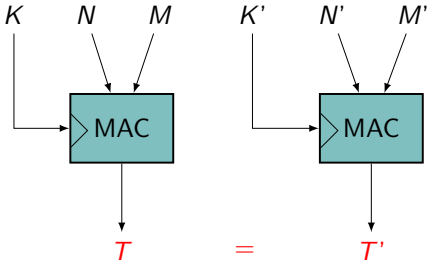

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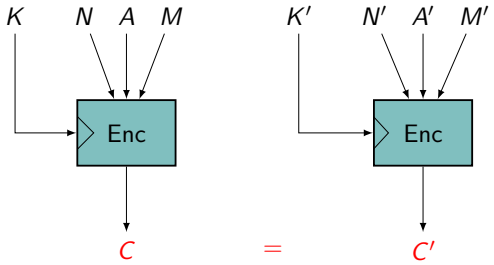

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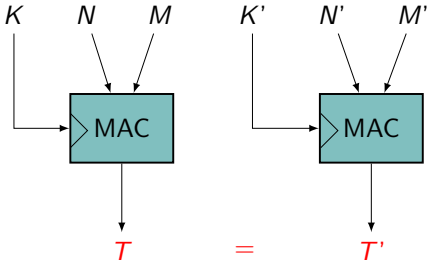

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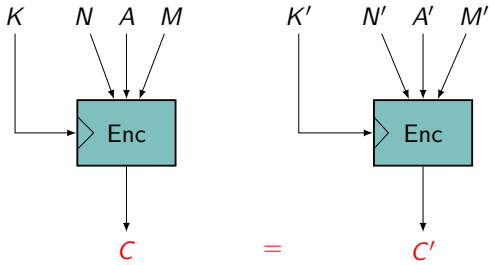

Notion	Requirement	[BH22]
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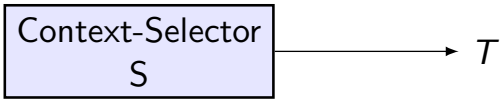

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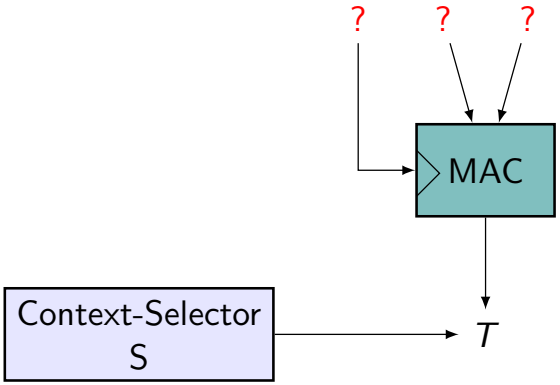
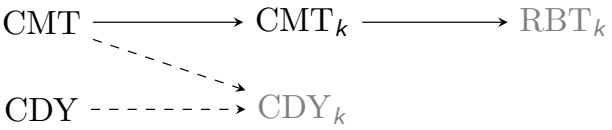


Relations between Commitment and Context-Discovery Notions



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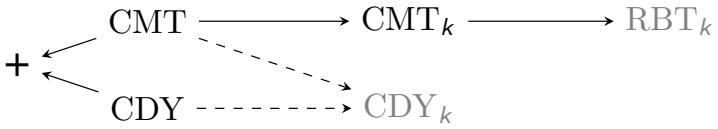

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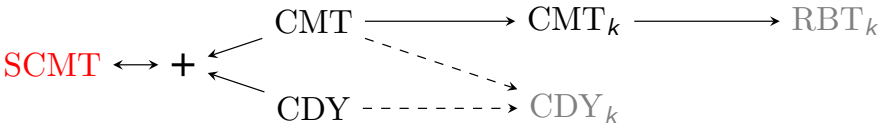

Security Analysis of Standardized MACs

Summary Table

Scheme	CMT_k	CMT	CDY
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HMAC with variable-length keys	no	no	?
Badger	no	no	no
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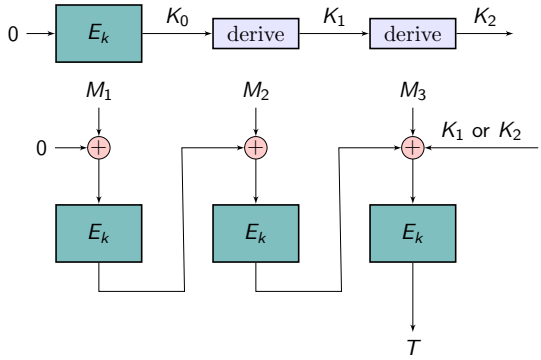
Key-Committing Attack on CMAC



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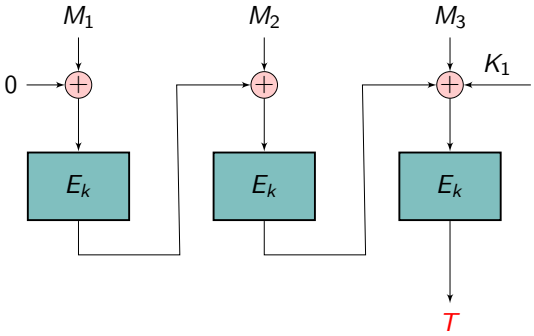
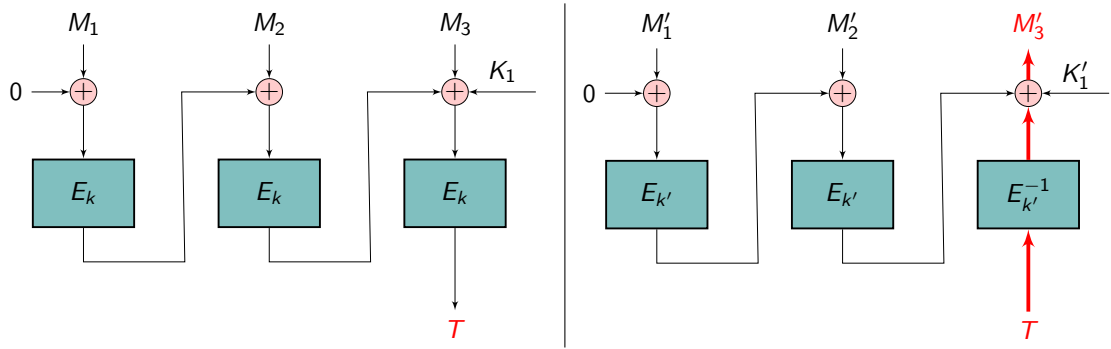
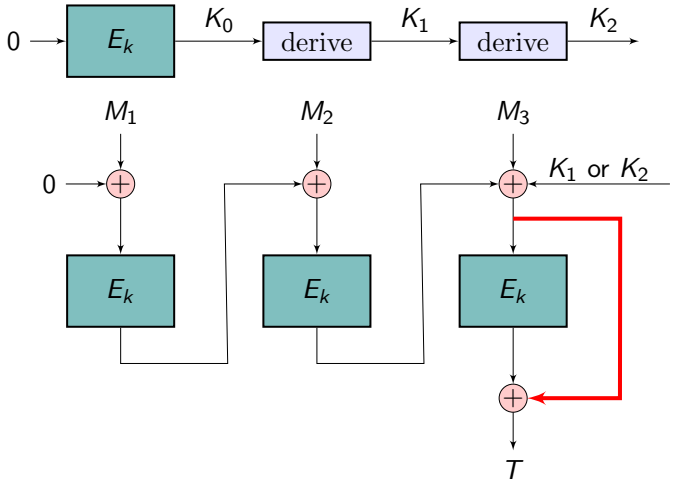


Key-Committing Attack on CMAC

$\rightarrow$ Choose the values k, k' such that $k \neq k'$



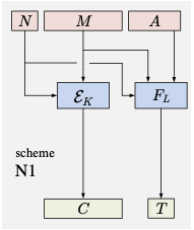
CMAC-C1: a Key-Committing Secure Variant of CMAC



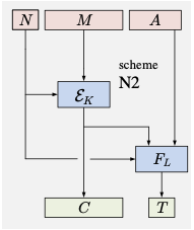
Applications to Generic Composition

Generic Composition Paradigms [NRS14]

Encrypt-and-MAC (EaM)



Encrypt-then-MAC (EtM)



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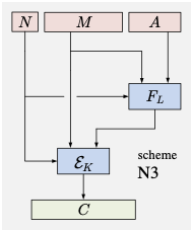
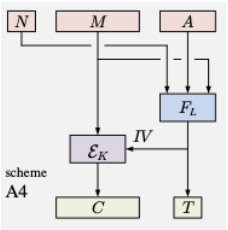
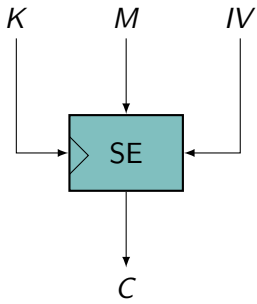


SIV



Key-Committing Insecurity of IV-Based Symmetric Encryption



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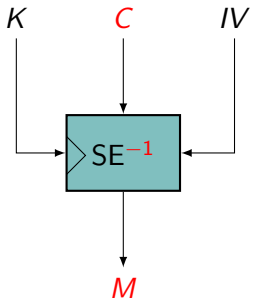

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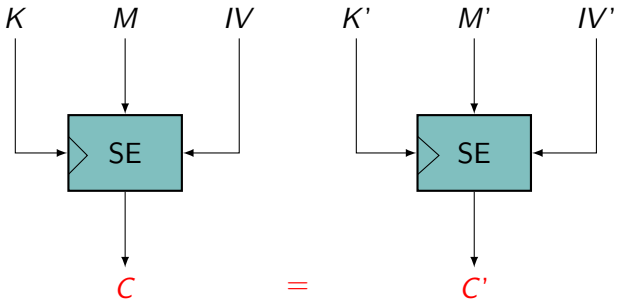

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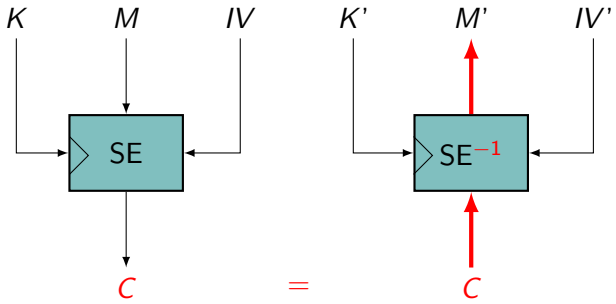

Generic Composition without Assumptions on IV-Based Encryption

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If the MAC is CDY

$\rightarrow$

Encrypt-then-MAC, Encrypt-and-MAC and SIV are CDY

Generic Composition without Assumptions on IV-Based Encryption

If the MAC is CDY

$\rightarrow$

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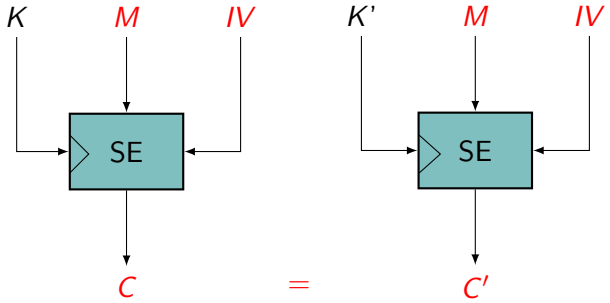
If the MAC is CMT_k or CMT

$\rightarrow$

Encrypt-then-MAC and Mac-then-Encrypt are not necessarily

Key-Robustness Security (RBT_k) of IV-Based Encryption



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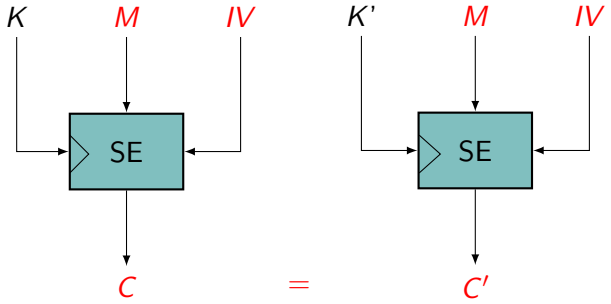
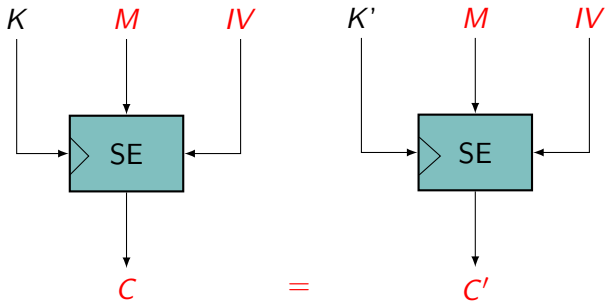


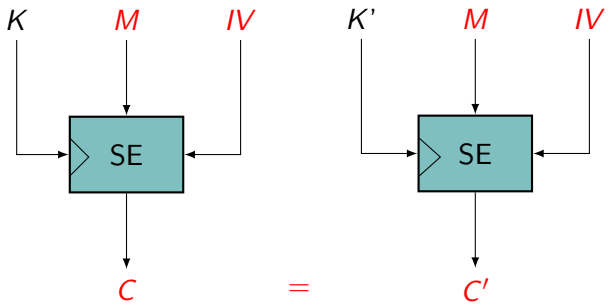
- CTR and CBC encryption mode are RBT_k

Key-Robustness Security (RBT_k) of IV-Based Encryption



- CTR and CBC encryption mode are RBT_k
- If SE is RBT_k and the MAC is $\mathrm{CMT} \rightarrow$ Encrypt-and-MAC and SIV are CMT

Key-Robustness Security (RBT_k) of IV-Based Encryption



- CTR and CBC encryption mode are RBT_k
- If SE is RBT_k and the MAC is CMT $\rightarrow$ Encrypt-and-MAC and SIV are CMT
  $\rightarrow$ Encrypt-then-MAC and MAC-then-Encrypt are not

Generic Composition with a Key Schedule

- Keys for MAC and SE are derived from a single key with a Key Schedule function:

$$\mathsf{KS}(K) = (K_m, K_e)$$

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If Key Schedule is COLL and the MAC is CMT_k, CMT or CDY

$\rightarrow$

Encrypt-then-MAC, Encrypt-and-MAC and SIV are CMT_k, CMT or CDY

Summary of Analyses

	MAC Assumption	SCMT	CDY	CDY_k	CMT	CMT_k
Scheme	SE/KS Assumption					
MtE	none	?	?	?	no	no
MtE	RBT_k	?	?	?	no	no
EtM	none	no	yes	yes	no	no
EtM	RBT_k	no	yes	yes	no	no
KEtM	COLL	yes	yes	yes	yes	yes
EaM	none	?	yes	yes	?	?
EaM	RBT_k	yes	yes	yes	yes	?
KEaM	COLL	yes	yes	yes	yes	yes
SIV	none	?	yes	yes	?	?
SIV	RBT_k	yes	yes	yes	yes	?
KSIV	COLL	yes	yes	yes	yes	yes

Summary of Analyses

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MtE	RBT_k	?	?	?	no	no
EtM	none	no	yes	yes	no	no
EtM	RBT_k	no	yes	yes	no	no
KEtM	COLL	yes	yes	yes	yes	yes
EaM	none	?	yes	yes	?	?
EaM	RBT_k	yes	yes	yes	yes	?
KEaM	COLL	yes	yes	yes	yes	yes
SIV	none	?	yes	yes	?	?
SIV	RBT_k	yes	yes	yes	yes	?
KSIV	COLL	yes	yes	yes	yes	yes

Summary of Analyses

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MtE	RBT_k	?	?	?	no	no
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EtM	RBT_k	no	yes	yes	no	no
KEtM	COLL	yes	yes	yes	yes	yes
EaM	none	?	yes	yes	?	?
EaM	RBT_k	yes	yes	yes	yes	?
KEaM	COLL	yes	yes	yes	yes	yes
SIV	none	?	yes	yes	?	?
SIV	RBT_k	yes	yes	yes	yes	?
KSIV	COLL	yes	yes	yes	yes	yes

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MtE	RBT_k	?	?	?	no	no
EtM	none	no	yes	yes	no	no
EtM	RBT_k	no	yes	yes	no	no
KEtM	COLL	yes	yes	yes	yes	yes
EaM	none	?	yes	yes	?	?
EaM	RBT_k	yes	yes	yes	yes	?
KEaM	COLL	yes	yes	yes	yes	yes
SIV	none	?	yes	yes	?	?
SIV	RBT_k	yes	yes	yes	yes	?
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Summary of Analyses

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MtE	none	?	?	?	no	no
MtE	RBT_k	?	?	?	no	no
EtM	none	no	yes	yes	no	no
EtM	RBT_k	no	yes	yes	no	no
KEtM	COLL	yes	yes	yes	yes	yes
EaM	none	?	yes	yes	?	?
EaM	RBT_k	yes	yes	yes	yes	?
KEaM	COLL	yes	yes	yes	yes	yes
SIV	none	?	yes	yes	?	?
SIV	RBT_k	yes	yes	yes	yes	?
KSIV	COLL	yes	yes	yes	yes	yes

Summary of Analyses

	MAC Assumption	SCMT	CDY	CDY_k	CMT	CMT_k
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MtE	none	?	?	?	no	no
MtE	RBT_k	?	?	?	no	no
EtM	none	no	yes	yes	no	no
EtM	RBT_k	no	yes	yes	no	no
KEtM	COLL	yes	yes	yes	yes	yes
EaM	none	?	yes	yes	?	?
EaM	RBT_k	yes	yes	yes	yes	?
KEaM	COLL	yes	yes	yes	yes	yes
SIV	none	?	yes	yes	?	?
SIV	RBT_k	yes	yes	yes	yes	?
KSIV	COLL	yes	yes	yes	yes	yes

Future Work

- Analyze the remaining generic composition combinations

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