The Limited Power of Verification Queries in Message Authentication and Authenticated Encryption

September 29, 2015

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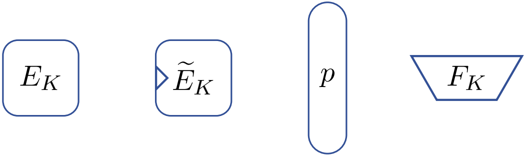
Modes of Operation



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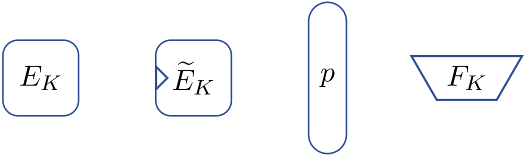

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2. AE: confidentiality and authenticity

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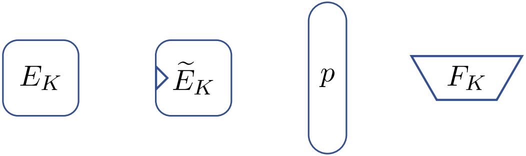

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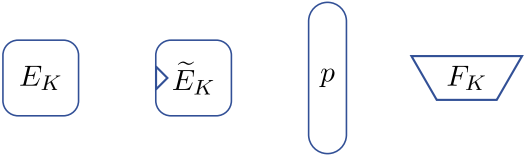

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Advantage of modes: able to focus on primitive

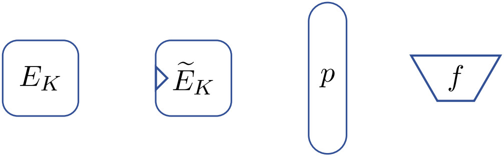
Reduction Loss

1. Reduction is often not perfect, results in a loss of security
2. Loss of security quantified in terms of parameters

Table: Examples of parameters.

n	Block size
k	Key length
q	Number of tagging or encryption queries
v	Number of verification queries
ℓ	Maximum message length
σ	Total number of encryption *and* decryption blocks

Various AE Bounds



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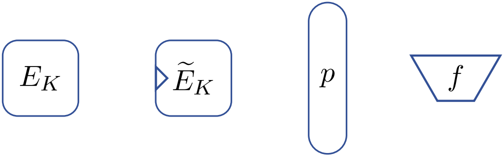

Example:	AES-OTR	Deoxys	ASCON	OMD
Confidentiality:	$\frac{\sigma^2}{2^n} + \mathsf{PRP}$	TPRP	$\frac{\sigma^2}{2^n}$	$\frac{\sigma^2}{2^n} + \mathsf{PRF}$

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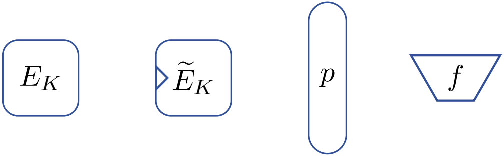

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Confidentiality:	$\frac{\sigma^2}{2^n}$ + PRP	TPRP	$\frac{\sigma^2}{2^n}$	$\frac{\sigma^2}{2^n}$ + PRF
Authenticity:	$+\frac{v}{2^n}$	$+\frac{v}{2^n}$	$+\frac{v}{2^n}$	$+\frac{v}{2^n}$

Improved Bounds: MAC Message Length

$$\frac{\ell^2 q^2}{2^n} \longrightarrow \frac{\ell q^2}{2^n}$$

PMAC, CBC-MAC, EMAC, OMAC, TMAC

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$n = 128, q = 2^{48}$:

$$\ell \leq 2^{15} \longrightarrow \ell \leq 2^{30}$$

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$n = 128, \ell = 2^{15}$:

$$q \leq 2^{48} \longrightarrow q \leq 2^{63}$$

Improved Bounds: Permutation Based Modes

	b	c	r	κ	**security**
Ascon	320	192	128	96	**96**
	320	256	64	128	**128**
CBEAM	256	190	66	128	**128**
ICEPOLE	1280	254	1026	128	**128**
	1280	318	962	256	**256**
Keyak	800	252	548	128	**128**
	1600	252	1348	128	**128**
NORX	512	192	320	128	**128**
	1024	384	640	256	**256**
GIBBON/ HANUMAN	200	159	41	80	**80**
	280	239	41	120	**120**
STRIBOB	512	254	258	192	**192**

Improved Bounds: Permutation Based Modes

	b	c	r	$\frac{r}{r_{\text{old}}}$	κ	**security**
Ascon	320	96	224	1.75	96	**96**
	320	128	192	3	128	**128**
CBEAM	256	128	128	1.94	128	**128**
ICEPOLE	1280	128	1152	1.12	128	**128**
	1280	256	1024	1.06	256	**256**
Keyak	800	128	672	1.23	128	**128**
	1600	128	1472	1.09	128	**128**
NORX	512	128	384	1.2	128	**128**
	1024	256	768	1.2	256	**256**
GIBBON/ HANUMAN	200	80	120	2.93	80	**80**
	280	120	160	3.90	120	**120**
STRIBOB	512	192	320	1.24	192	**192**

Improved security bounds leads to

1. Better parameter choices
2. Increased longevity
3. Increased efficiency

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Despite advances, there is still a lot of work left.

Authenticity Definition

Auth(q, v): forgery success with q tagging queries and v forgery attempts

Authenticity Bounds

$$\frac{\sigma^2}{2^n} \longrightarrow \frac{\ell^2(q + v)^2}{2^n}$$

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1. 128 bit block cipher

$$\frac{\ell^2(q+v)^2}{2^{128}}$$

Authenticity Bounds

$$\frac{\sigma^2}{2^n} \longrightarrow \frac{\ell^2(q + v)^2}{2^n}$$

1. 128 bit block cipher
2. Only one-block verification queries

$$\frac{1^2(0 + v)^2}{2^{128}}$$

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$$\frac{v^2}{2^{128}}$$

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$$\frac{v^2}{2^{128}} \quad \text{vs} \quad \frac{v}{2^{128}}$$

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$$v = 2^{64}: \quad 1 \quad \text{vs} \quad \frac{1}{2^{64}}$$

Optimal Bound

So far only certain types of MACs have optimal bound:

1. Nonce-based
2. Multiple keys

Excludes PMAC, CBC-MAC, OMAC

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For AE

1. except for TBC modes, none with optimal bounds
2. Generic composition: reduction to MAC-security
   $\rightarrow$ need optimal MACs

Question

Why do well-designed schemes exhibit quadratic dependence?

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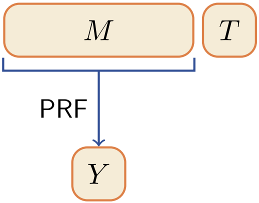
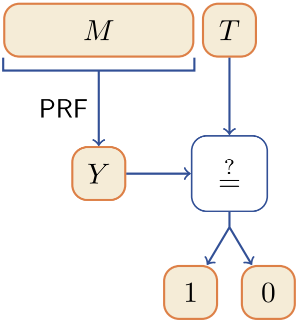
Proof techniques

PRF-based MAC



PRF-based MAC



Generic Reduction

Best possible generic reduction:

$$\mathsf{Auth}(q, v)$$

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PMAC

$$\frac{v}{2^n} + c \cdot \frac{\ell(q + v)^2}{2^n}$$

PRP-PRF Switch

PRP-PRF Switch: $\dfrac{0.5\sigma^2}{2^n}$

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GCM with nonce length fixed to 96 bits

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GCM with nonce length fixed to 96 bits

Confidentiality:

$$\underbrace{\frac{0.5(\sigma + q + 1)^2}{2^n}}_{\text{PRP-PRF switch}}$$

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GCM with nonce length fixed to 96 bits

Confidentiality:

$$\underbrace{\frac{0.5(\sigma+q+1)^2}{2^n}}_{\text{PRP-PRF switch}}$$

Authenticity:

$$\underbrace{\frac{0.5(\sigma+q+v+1)^2}{2^n}}_{\text{PRP-PRF switch}}+\frac{v(\ell+1)}{2^\tau}$$

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Paper in the works

1. Generalizing known techniques, applied to GCM to recover bound
2. Analyze block cipher based modes in detail, applied to PMAC to recover bound