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

September 29, 2015

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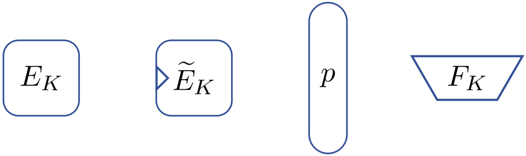
Modes of Operation



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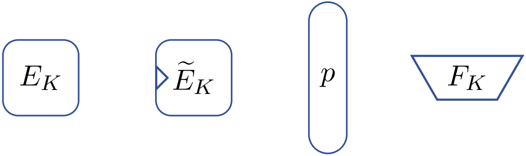

Example: AES-OTR Deoxys ASCON OMD

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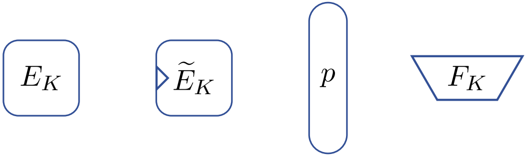

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Advantage of modes: able to focus on primitive

1. Reduce security of AE scheme to that of underlying primitive
2. For AE this is done for confidentiality and authenticity

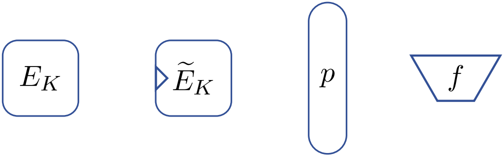
Reduction Loss

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

Various AE Bounds



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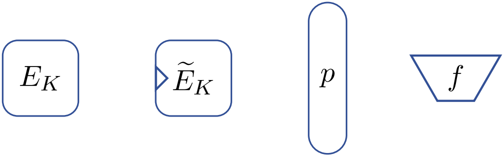

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Confidentiality:	$\frac{\sigma^2}{2^n}$ + (S)PRP	0	$\frac{\sigma^2}{2^n}$	$\frac{\sigma^2}{2^n}$ + PRF

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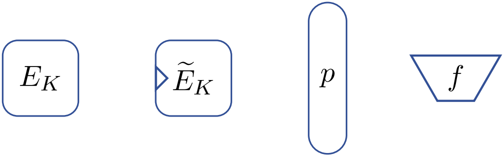

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Authenticity:	$+\frac{v}{2^n}$	$+\frac{v}{2^n}$	$+\frac{v}{2^n}$	$+\frac{v}{2^n}$

Improved Bounds: MAC Message Length

Much research performed reducing message length dependence from quadratic to linear for MACs: PMAC, CBC-MAC, EMAC, OMAC, TMAC

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Improved Bounds: Permutation Based Modes

	c	n	k	security
Ascon	192	128	96	96
	256	64	128	128
ICEPOLE	254	1026	128	128
	318	962	256	256
NORX	192	320	128	128
	384	640	256	256
GIBBON/ HANUMAN	159	41	80	80
	239	41	120	120

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Improved Bounds: Permutation Based Modes

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	128	192	3	128	128
ICEPOLE	128	1152	1.12	128	128
	256	1024	1.06	256	256
NORX	128	384	1.2	128	128
	256	768	1.2	256	256
GIBBON/ HANUMAN	80	120	2.92	80	80
	120	160	3.90	120	120

Improved security bounds leads to

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

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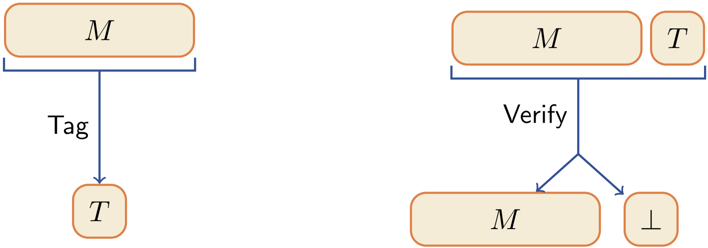
Despite advances, there is still a lot of work left.

Authenticity Definition



$\mathsf{Auth}(q, v)$: forgery success with q tagging queries and v forgery attempts

Authenticity Bounds

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

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1. 128 bit block cipher

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

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

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

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

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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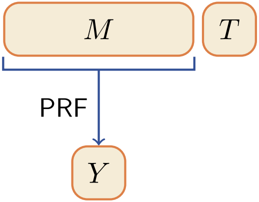
Proof techniques

PRF-based MAC



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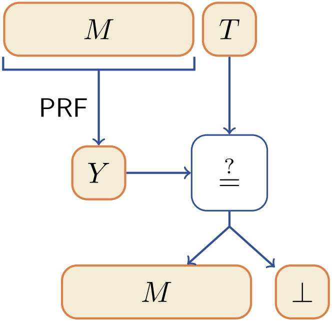

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PMAC

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

PRP-PRF Switch

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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