Reconsidering generic composition

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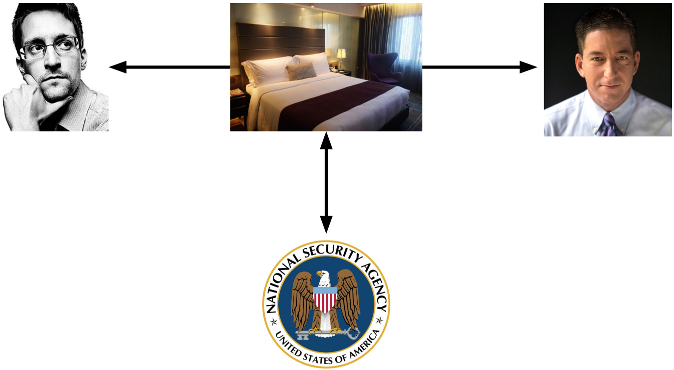
We want to ensure messages are unaltered and confidential.



Authenticated encryption is the solution to this problem.

Authenticated Encryption (AE)

AE provides

- Confidentiality
- Integrity
- Authentication

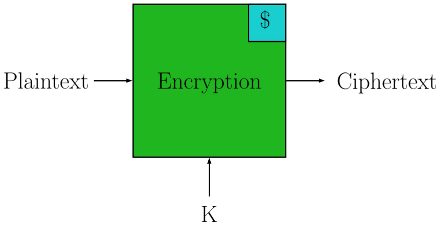
Generic composition: construction of Authenticated Encryption with an encryption scheme and a MAC.
Dedicated schemes: CCM, GCM or the ongoing CAESAR competition also provide authenticated encryption.

Generic composition

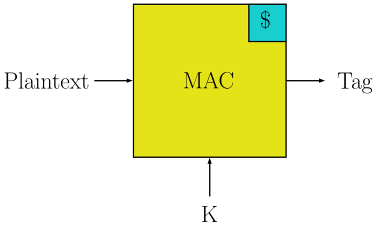
- Combine a MAC and an encryption scheme together as black boxes.
- Uses off the shelves schemes.
- First results in 2000, problem revisited in 2014.

Probabilistic schemes

First results of 2000 assumes we have probabilistic schemes.



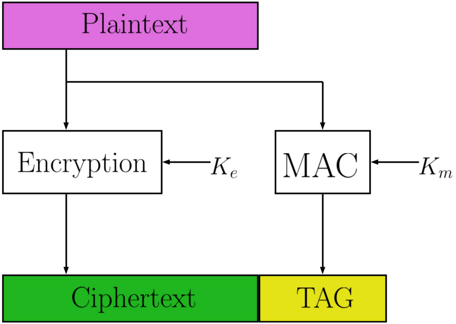
$E(K_e, M) = C$



$T(K_m, M) = Tag$

Encrypt-and-MAC (E&M)

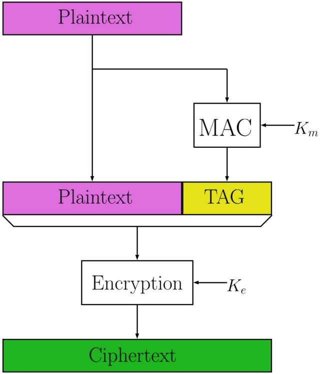
$$\overline{E}(K_e||K_m, M) = E(K_e, M)||T(K_m, M)$$



We can compute $E(K_e, M)$ and $T(K_m, M)$ in parallel.
The SSH protocol is implementing this construction.

MAC-then-Encrypt (MtE)

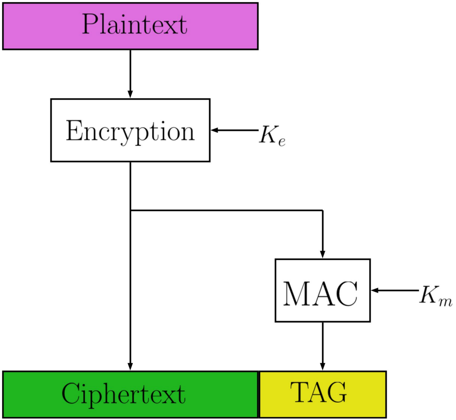
$$\overline{E}(K_e||K_m, M) = E(K_e, M||T(K_m, M))$$



The MAC is encrypted, so harder to attack.
SSL/TLS is implementing this construction.

Encrypt-then-MAC (EtM)

$\overline{E}(K_e||K_m, M) = C||T(K_m, C)$ where $C = E(K_e, M)$



We calculate the MAC of the ciphertext, not the plaintext.
EtM is implemented in IPSec.

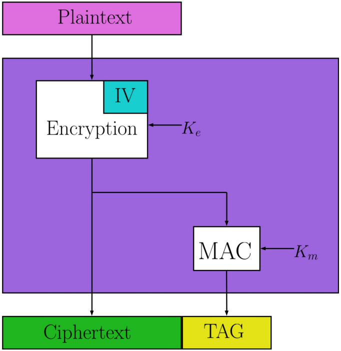
Security of M&E, MtE and EtM

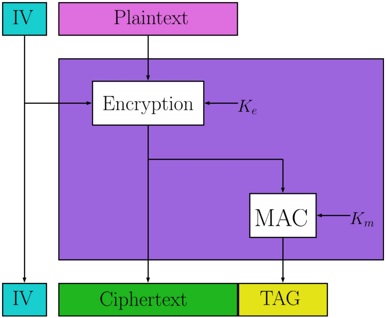
Bellare and Namprempre, 2000

- M&E: MAC can leak information about the message.
- MtE: We can create a new valid ciphertext if the encryption is malleable.
- EtM: Proven secure if the encryption and the MAC are secure.

Is that the end?

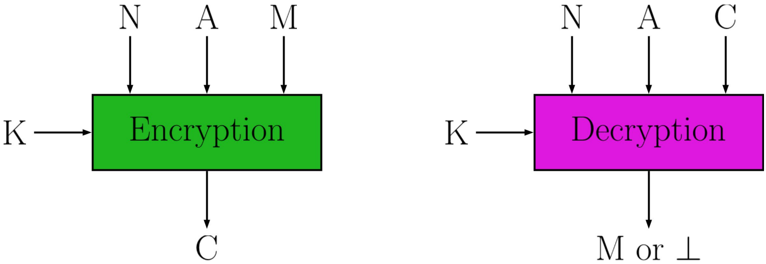
Real schemes do not match. We use a nonce or an initialization vector (IV) external to the schemes.





nAE scheme

$E_K^{N,A}(M) = C$ and $D_K^{N,A}(C) = M$ or $\perp$.



N: Nonce
A: Associated data
K: Secret key
M: Message
C: Ciphertext

nAE properties

Required properties:

- Correctness: if $E_K^{N,A}(M) = C \neq \perp$ then $D_K^{N,A}(C) = M$
- Tidiness: if $D_K^{N,A}(C) = M \neq \perp$ then $E_K^{N,A}(M) = C$

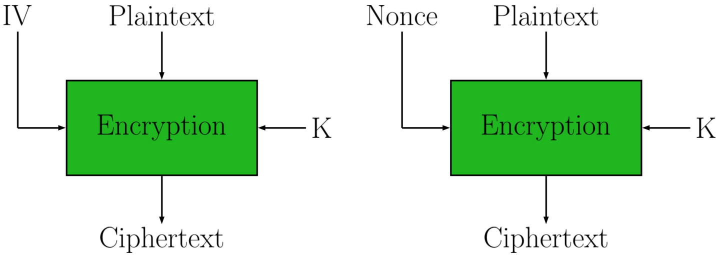
Security properties:

- The encryption output is indistinguishable from random strings in a chosen plaintext attack, the adversary must not repeat nonces.
- The adversary is unable to produce a new valid ciphertext given an encryption oracle. Again, the adversary must not repeat nonces.

nE and ivE

Encryption can be either nonce-based (nE) or IV-based (ivE).

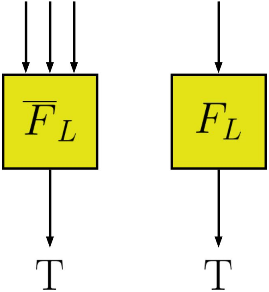
- IV: random initialization vector.
- Nonce: unique initialization vector.



Abstraction of the MAC

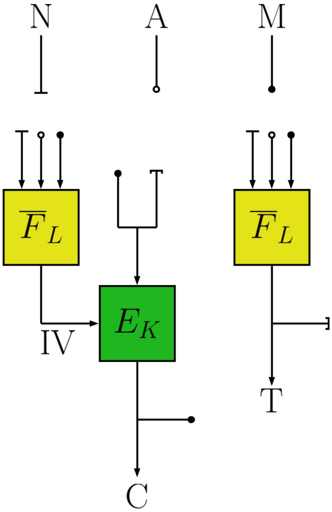
To simplify, we can abstract the MAC as a pseudo-random function.

- vecMAC: A MAC primitive that takes multiple values for its input (here, 3 maximum).
- strMAC: classic MAC as we know.



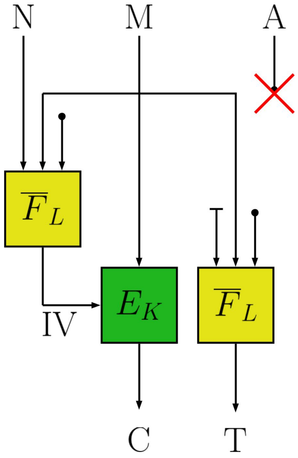
Combinations

Start by creating a basic model and enumerate all possibilities.
There are 160 possible combinations.



Method

Eliminate bad schemes by finding trivial attacks.

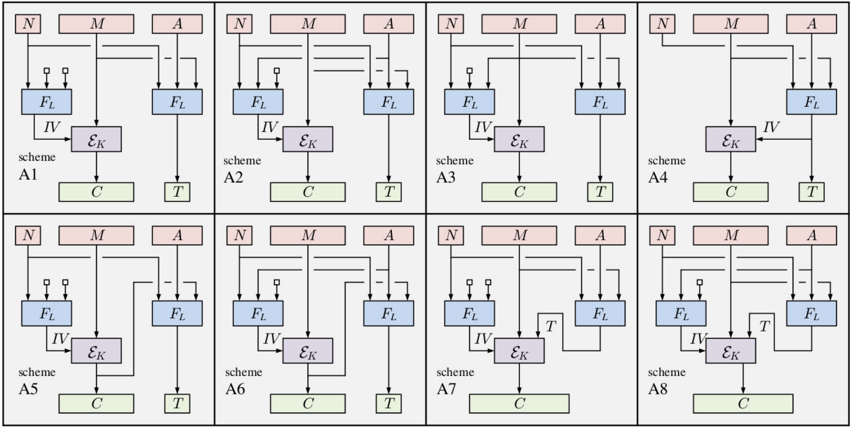


The remaining schemes were analyzed by hand.

A* Schemes

There were 160 candidates, 8 of them are favored (A1-A8), one has a weaker security bound (A9) and three are elusive (A10-A12).

Scheme	IV	Tag	Comment
A1	$F_L^{iv}(N, \sqcup, \sqcup)$	$F_L^{tag}(N, A, M)$	C,T done in parallel
A2	$F_L^{iv}(N, A, \sqcup)$	$F_L^{tag}(N, A, M)$	C,T done in parallel
A3	$F_L^{iv}(N, \sqcup, M)$	$F_L^{tag}(N, A, M)$	Assume IV is recoverable, untruncatable
A4	$F_L^{iv}(N, A, M)$	$F_L^{tag}(N, A, M)$	$F^{iv} = F^{tag}$, untruncatable, nonce-reuse secure
A5	$F_L^{iv}(N, \sqcup, \sqcup)$	$F_L^{tag}(N, A, C)$	M,T done in parallel
A6	$F_L^{iv}(N, A, \sqcup)$	$F_L^{tag}(N, A, C)$	M,T done in parallel
A7	$F_L^{iv}(N, \sqcup, \sqcup)$	$F_L^{tag}(N, A, M)$	Untruncatable
A8	$F_L^{iv}(N, A, \sqcup)$	$F_L^{tag}(N, A, M)$	Untruncatable
A9	$F_L^{iv}(N, A, \sqcup)$	$F_L^{tag}(N, \sqcup, M)$	Weaker bound, untruncatable
A10	$F_L^{iv}(N, A, \sqcup)$	$F_L^{tag}(\sqcup, A, M)$	Security unresolved
A11	$F_L^{iv}(N, A, \sqcup)$	$F_L^{tag}(\sqcup, \sqcup, M)$	Security unresolved
A12	$F_L^{iv}(N, \sqcup, \sqcup)$	$F_L^{tag}(\sqcup, A, M)$	Security unresolved



A1 to A3 is similar to E&M
A4 is SIV mode.
A5 and A6 is EtM.
A7 and A8 is MtE.

Image: Namprempre and al., *Reconsidering generic composition*

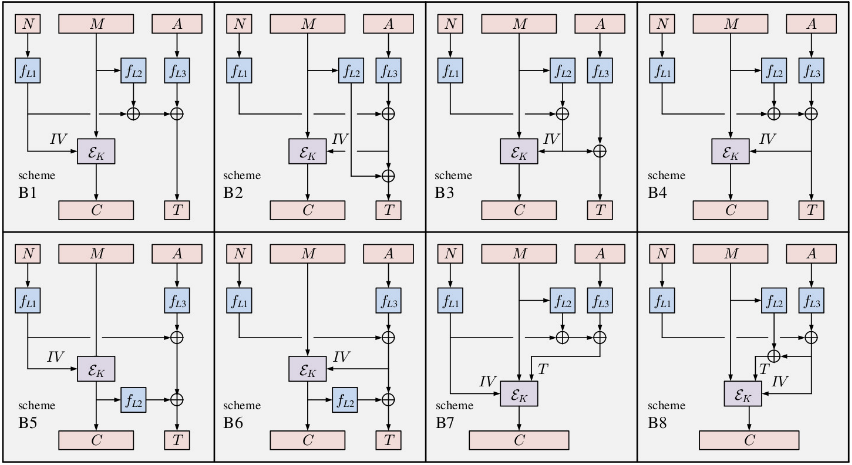
From strMAC to vecMAC

vecMAC is an abstract function, we need something concrete.
Use a *three-xor construction*.

$$F_{L1,L2,L3}(N, A, M) = f'_{L1}(N) \oplus f'_{L2}(A) \oplus f'_{L3}(M)$$

This transformation works for the eight A schemes and is proven secure. We now obtain the B schemes.

B Schemes



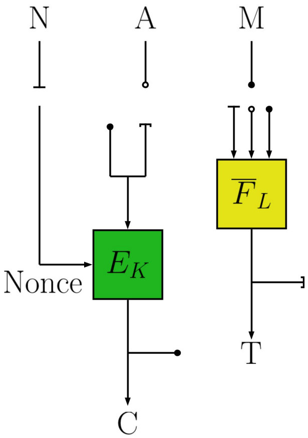
B1 is EAX mode.

Image: Namprempre and al., *Reconsidering generic composition*

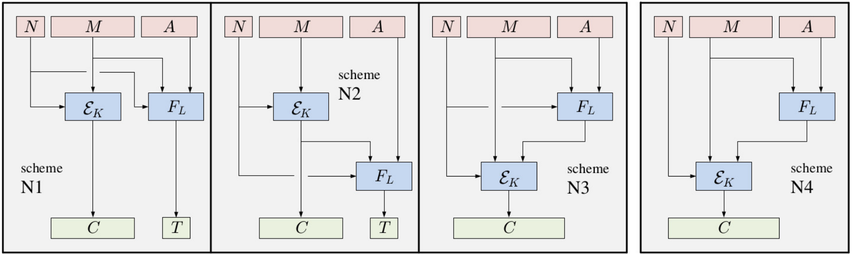
N Schemes

Another model with 20 candidates, three are favored and one is elusive.

We can again use the *three-xor construction*, but we keep the simplicity of vecMAC.



N Schemes



N1 can compute C and T in parallel.
N2 can compute M and T in parallel.
N3 is untruncatable.
N4 has an unresolved security, and C is untruncatable.

Image: Namprempre and al., *Reconsidering generic composition*

ISO 19772

Defines GCM, CCM and EAX very well, but EtM is poorly done.

- Usage of a Starting Value (SV). Unclear if it's a nonce or an IV.
- SV communication is not specified.
- What to do in case of a padding error?

We do not know if it's a scheme built from a pE, or from an ivE.

Conclusion

- Be careful when composing with cryptographic primitives. Additivity is not guaranteed.
- Interpreting cryptography and security results is not trivial. ISO 19772 is a pure example.
- The new result shown here is more concrete and applicable for real cryptography work.

Questions and Remarks?

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