Authenticated Encryption

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Secrecy and integrity

- We have primitives for secrecy and integrity
  - Secrecy: ciphers
  - Integrity: MAC
- What if we wish to achieve secrecy and integrity at the same time?

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Encrypt and authenticate

- Alice and Bob want to achieve both confidentiality and integrity

Alice (k1, k2)
message x
$y = E_{k1}(x)$
$t = MAC_{K2}(x)$

---------- [y, t] --------- >

Bob (k1, k2)
$x = D_{k1}(y)$
if $V_{k2}(x, t)$ return x
else return «error»

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Is it secure?

- The tag t might leak information about x
  - Nothing in the definition of security for a MAC implies that it hides information about x
- If the MAC is deterministic (e.g., CBC-MAC and HMAC), then it leaks whether the same message is encrypted twice

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Encrypt then authenticate

- Alice and Bob want to achieve confidentiality and integrity

Alice (k1, k2)
x
$y = E_{k1}(x)$
$t = MAC_{K2}(y)$
------- [y, t] --- >
Bob (k1, k2)
if $(V_{k2}(y, t))$ return $(x = D_{k1}(y))$
else return “error”

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Security of encrypt then authenticate

- It can be proved that if Enc is CPA-secure and MAC is secure then:
  - The combination is CPA-secure (encryption must be randomized)
  - The combination is a secure MAC

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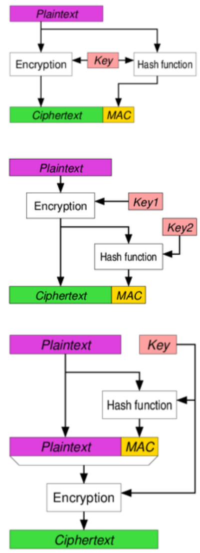
Three different approaches

- Encrypt and MAC (E&M)
  - Discouraged
  - SSH
- Encrypt then MAC (EtM)
  - Always correct
  - Ipsec
- MAC then Encrypt (MtE)
  - correctness depends on Enc-MAC combinations
  - TLS/SSL



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Authenticated Encryption

- Most of applications require *message privacy* and *message authentication*
- Combining privacy and authentication is a challenging task that is rarely done *securely* with *ad-hoc* constructions
- Authenticated Encryption (AE) are *encryption modes* which simultaneously assure the confidentiality and authenticity of data.

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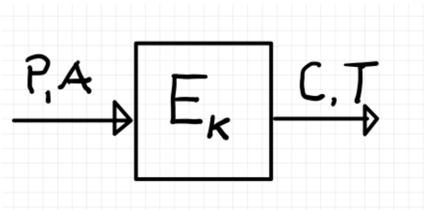
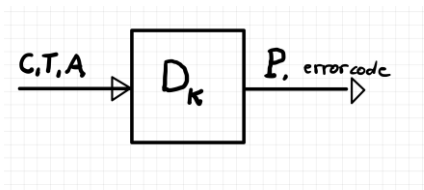
AE APIs

Encryption

Decryption





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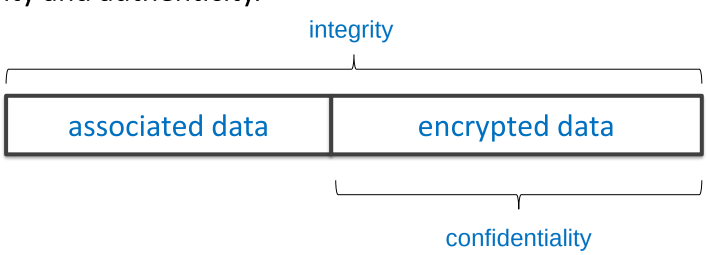
Authenticated Encryption with Associated Data (AEAD)

- AEAD allows checking the integrity of both the encrypted and unencrypted information in a message.
  - E.g., network packets or frames where the header needs visibility, the payload needs confidentiality, and both need integrity and authenticity.



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Standards and associated data

- NIST
  - CCM: CBC-MAC then CTR mode encryption
    - 802.11i
  - GCM: CTR mode encryption then MAC
    - Very efficient
- IETF
  - EAX: CTR mode encryption than OMAC
- NIST and IETF standards support AEAD

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Cipher Block Chaining Message Authentication Code (CCM)

- NIST SP 800-38C
- For IEEE 802.11 WiFi
- AES-CTR and CMAC
- Single key K

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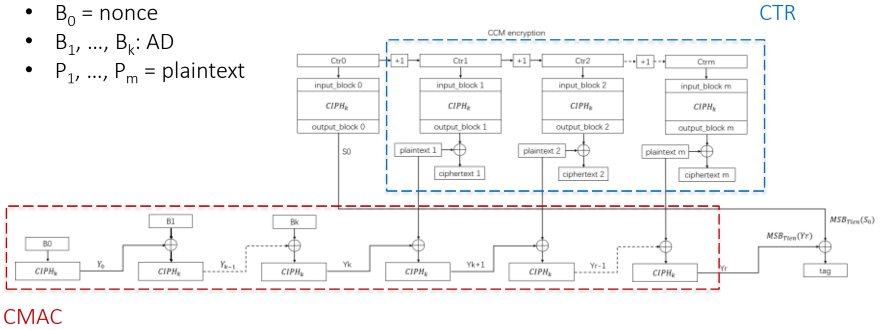
CCM – encryption flow chart

- B_0 = nonce
- B_1, …, B_k: AD
- P_1, …, P_m = plaintext



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CCM - drawbacks

- CCM is quite complex: it requires two passes through the plaintext

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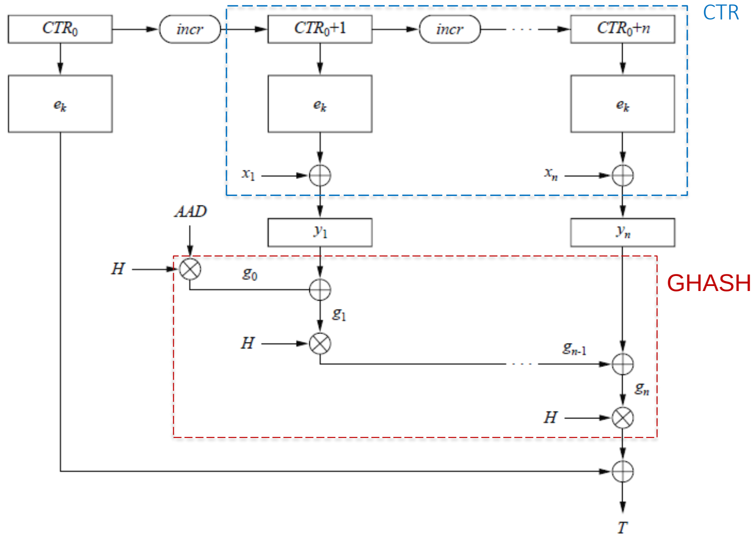
Galois Counter Mode (GCM)

- GCM is an encryption mode which also computes a MAC
  - Confidentiality and authenticity
- GCM protects
  - Confidentiality of a plaintext x
  - Authenticity of plaintext x and
  - Authenticity of AAD which is left in the clear

GCM - main components

- Cipher in the Counter Mode (CTR)
  - Confidentiality
  - Block size: 128 bit (e.g., AES-128)
- Galois field multiplication
  - Authentication
  - GMAC
    - Based on GHASH which exploits multiplication in $GF(2^{128})$
      - Irreducible polynomial $P(x) = x^{128} + x^7 + x^2 + x + 1$
      - Easy and efficient in HW

GCM – flow chart



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GCM - advantage

- Assume that AAD and ciphertext constitute a sequence of blocks X = X_1, X_2, …, X_m
- GHASH(X, H)
  - $Y_0 = 0^{128}$
  - $Y_i = (Y_{i-1} \oplus X_i) \cdot H$ which can be re-written as
  - $(X_1 \cdot H^m) \oplus (X_2 \cdot H^{m-1}) \oplus \cdots \oplus (X_{m-1} \cdot H^2) \oplus (X_m \cdot H^1)$
  - H^2, H^3, …, H^m can be *precomputed*
  - Xi's can be processed *in parallel*

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