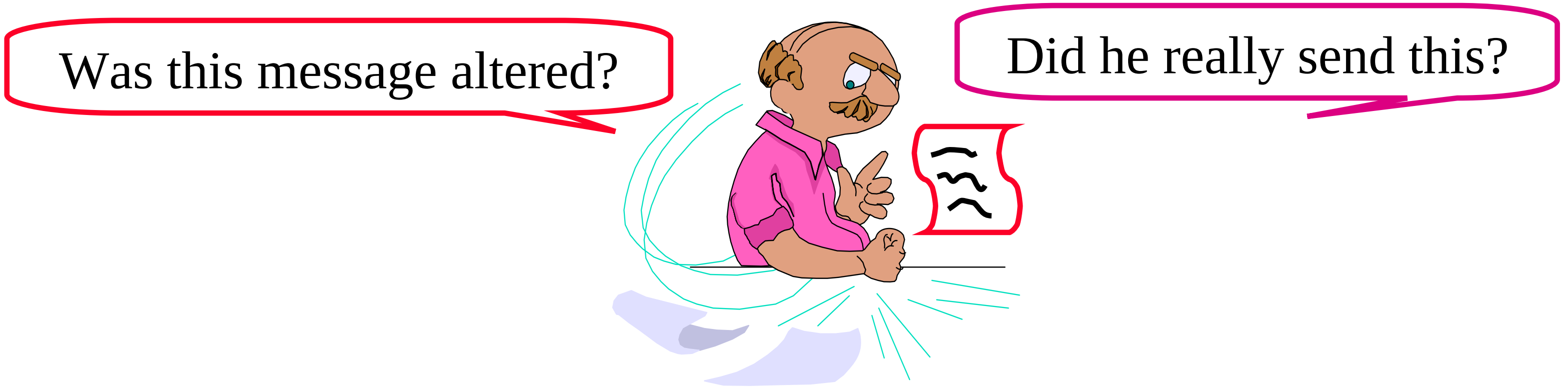
Message Authentication Codes



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1. Message Authentication
2. MACS based on Hash Functions: HMAC
3. MACs based on Block Ciphers: DAA and CMAC
4. Authenticated Encryption: CCM and GCM
5. Pseudorandom Number Generation Using Hash Functions and MACs

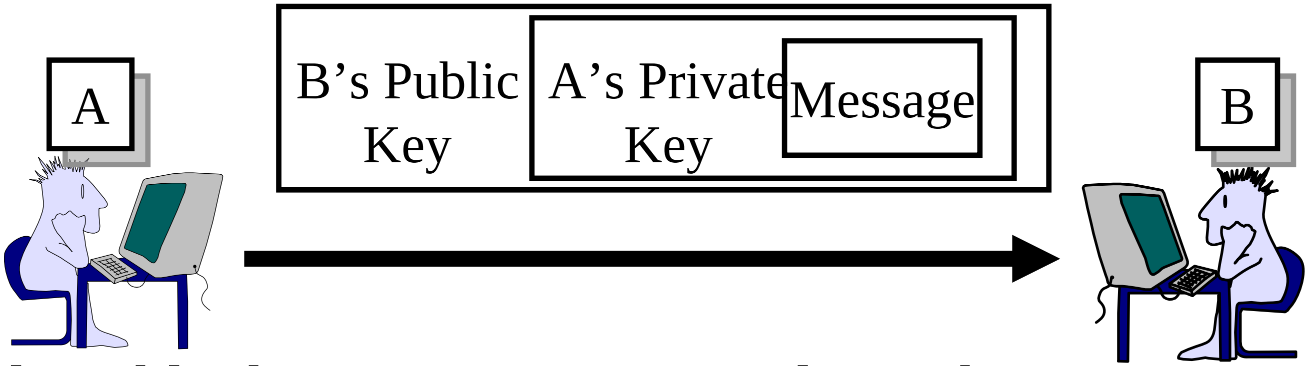
These slides are based partly on Lawrie Brown's slides supplied with William Stallings's book "Cryptography and Network Security: Principles and Practice," 6th Ed, 2013.

Message Security Requirements

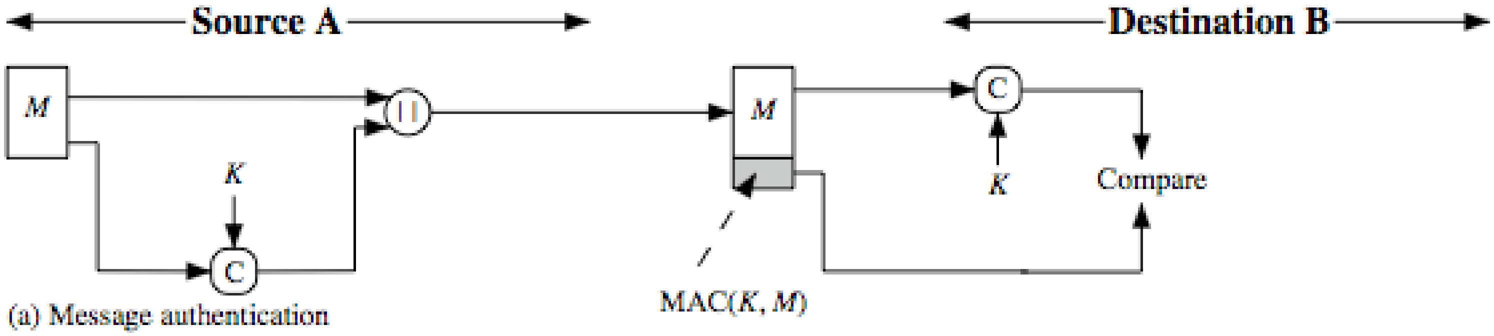
- Disclosure
- Traffic analysis
- Masquerade
- Content modification
- Sequence modification
- Timing modification
- Source repudiation
- Destination repudiation

Message Authentication = Integrity + Source Authentication

Public-Key Authentication and Secrecy



- Double public key encryption provides authentication and integrity. Double public key ⇒ Very compute intensive
- Crypto checksum (MAC) is better.
  Based on a secret key and the message.
  Can also encrypt with the same or different key.



MAC Properties

- A MAC is a cryptographic checksum
  $MAC = C_K(M)$
  - Condenses a variable-length message M using a secret key
  - To a fixed-sized authenticator
- Is a many-to-one function
  - Potentially many messages have same MAC
  - But finding these needs to be very difficult
- Properties:
  1. It is infeasible to find another message with same MAC
  2. MACs should be uniformly distributed
  3. MAC should depend equally on all bits of the message
- Public key MACs provide non-repudiation.
  Secret key MACs do not.

Security of MACs

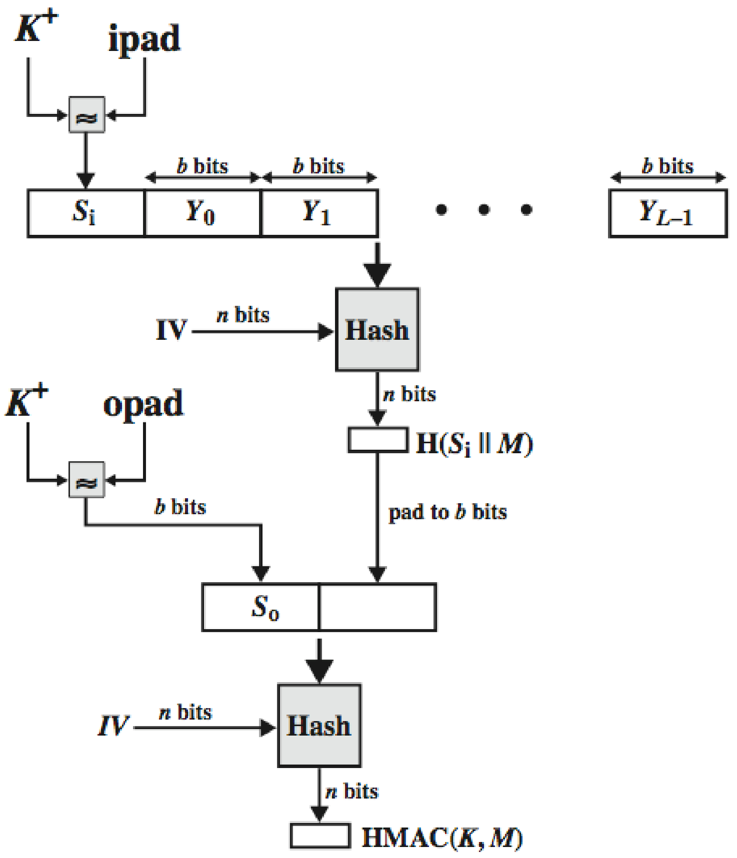
- **Brute-force** attacks exploiting
  - Strong collision resistant hash have cost min(2^k, 2^n), k=size of key, n=size of the hash
  - MACs with known message-MAC pairs
    - Can either attack keyspace (cf key search) or hash
    - 128-bit hash looks vulnerable, 160-bits better

HMAC Design Objectives

- Keyed Hash ⇒ includes a key along with message
- HMAC is a general design. Can use any hash function ⇒ HMAC-MD5, HMAC-AES
- Uses hash functions without modifications
- Allow for easy replace-ability of embedded hash function
- Preserve original performance of hash function without significant degradation
- Uses and handles keys in a simple way.
- Has well understood cryptographic analysis of authentication mechanism strength

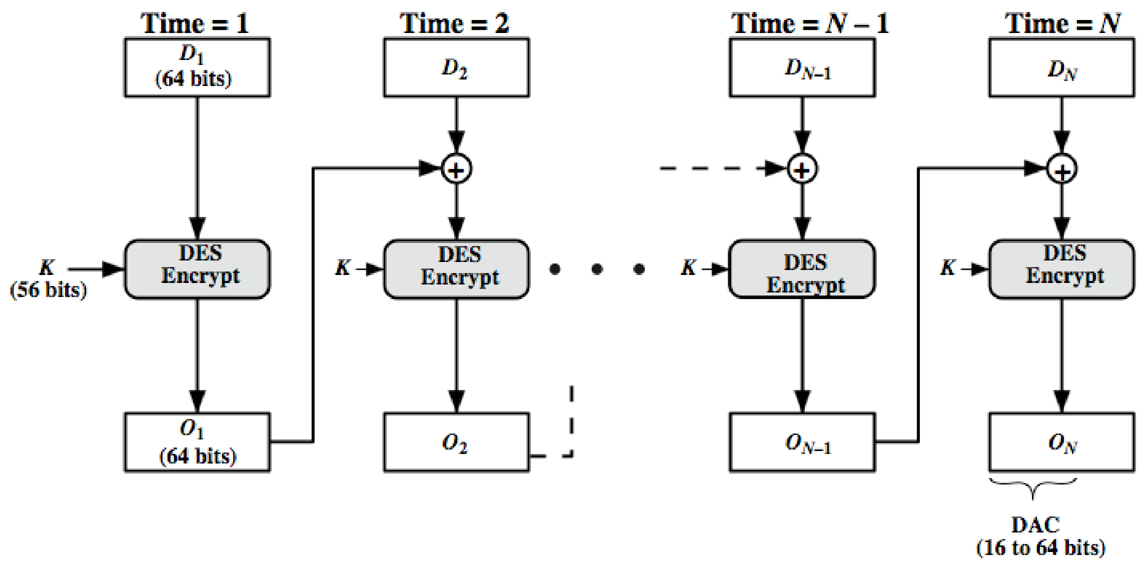
HMAC

- RFC2104
- Uses hash function on the message:
  $HMAC_K(M) =$
  $H[(K^+ \oplus opad) || H[(K^+ \oplus ipad) || M)]]$
  - Where K^+ = key padded to b-bits or hashed to b-bits if |k|>b
  - b = block size for the hash
  - opad, ipad are constants
  - ipad = 36 repeated b/8 times
    opad = 5C repeated b/8 times
- Any hash function can be used
  - E.g., MD5, SHA-1, RIPEMD-160, Whirlpool
- Proved that security of HMAC relates to that of the underlying hash algorithm



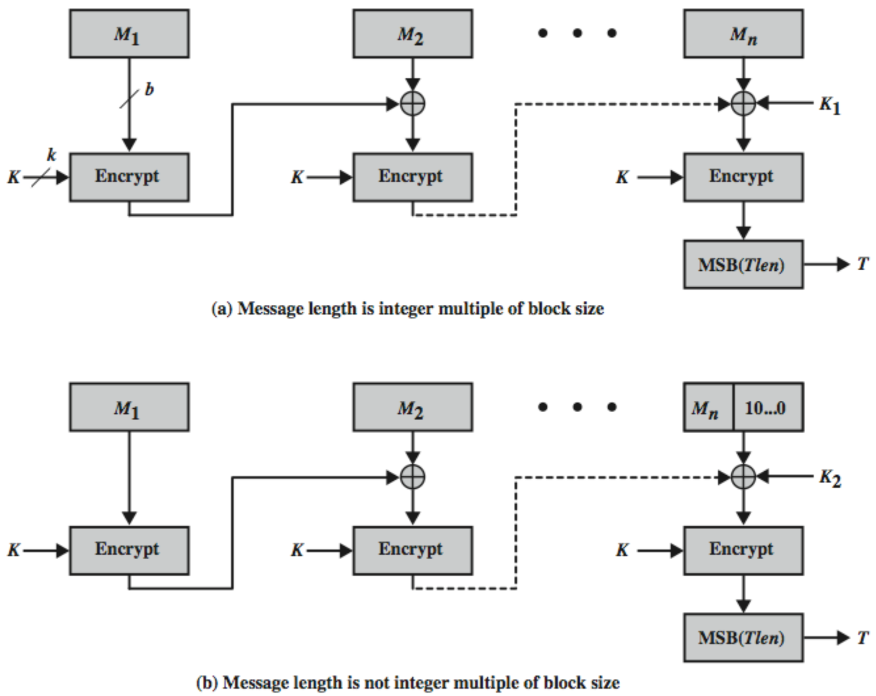
Using Symmetric Ciphers for MACs

- Can use any block cipher chaining mode and use final block as a MAC
- **Data Authentication Algorithm (DAA)** = DES-CBC
  - Using IV=0 and zero-pad of final block
- For single block message X, T=MAC(K, X)
  Weakness: T is also MAC of 2-block message X||(X⊕T)



Cipher-based Message Authentication Code (CMAC)

- Black and Rogaway fixed DAA problem by using 3 keys. Iwata updated by generating 3 keys from a single key.
- Adopted by NIST SP800-38B
- Two n-bit keys from a k-bit encryption key
- $L=E(K,0^n)$
- $K_1=L\cdot x$
- $K_2=L\cdot x^2$
- $\cdot$=Multiplication in $GF(2^n)$
- Using a irreducible polynomial with min 1's
  - $x^{64}+x^4+x^3+x+1$ for 64 bits
  - $x^{128}+x^7+x^2+x+1$ for 128 bits



Authenticated Encryption

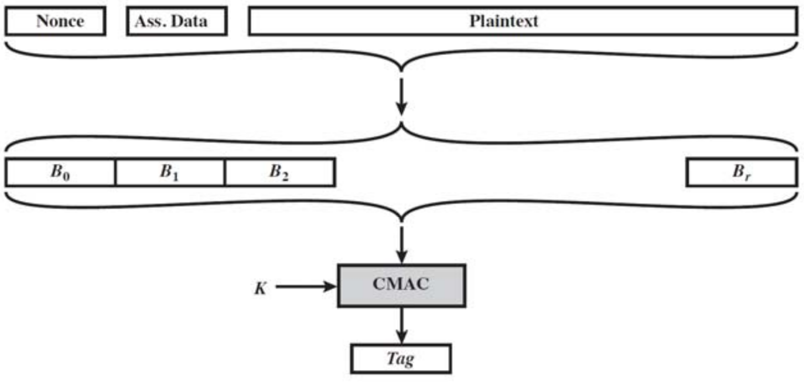
- Confidentiality + Integrity:

1. Hash-then-encrypt: E(K, (M || H(M))
2. MAC-then-encrypt: $E(K_2, (M \| MAC(K_1, M))$
   Used in SSL/TLS
3. Encrypt-then-MAC: $(C=E(K_2, M), T=MAC(K_1, C)$
   Used in IPsec
4. Encrypt-and-MAC: $(C=E(K_2, M), T=MAC(K_1, M)$
   Used in SSH

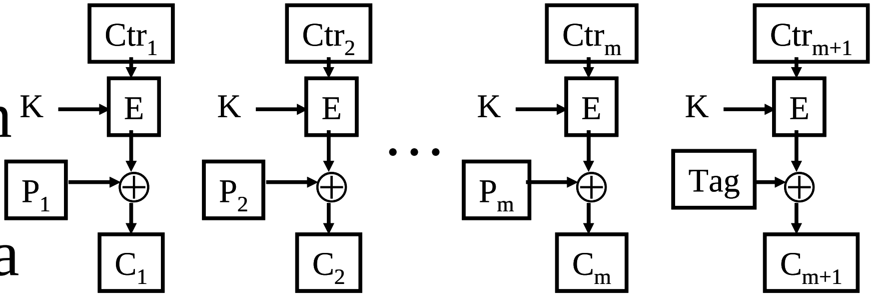
- But security vulnerabilities with all these
- NIST fixed these vulnerabilities with CCM and GCM

CCM

- Counter with Cipher Block Chaining-MAC
- NIST SP 800-38C for WiFi
- Algorithmic ingredients
  - AES encryption algorithm
  - CTR mode of operation
  - CMAC authentication algorithm
- Single key for both encryption & MAC
- Counters are generated using a counter generation function
- 2 passes over plaintext: MAC+E
- Associate data = headers in clear

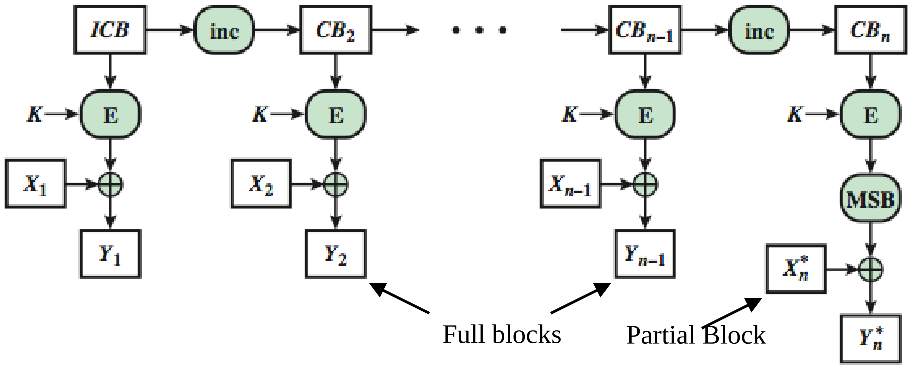


(a) Authentication

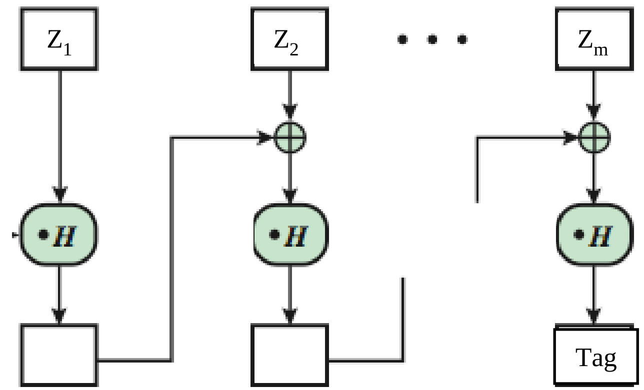


Galois/Counter Mode (GCM)

- NIST standard SP 800-38D, parallelizable
- Uses two functions:
  - GCTR - CTR mode with incremented counter
  - GHASH - a keyed hash function
- GHASH: plaintext xor'ed with feedback and *multiplied* with hash key H in GF(2^{128}) to generate authenticator tag $H=E[K,0^{128}]$
- Z_i's are constructed from the encrypted text Y_i and associated data
- MAC-only mode also



(b) $GCTR_K(ICB, X_1 \| X_2 \| \ldots \| X_n^*) = Y_n^*$



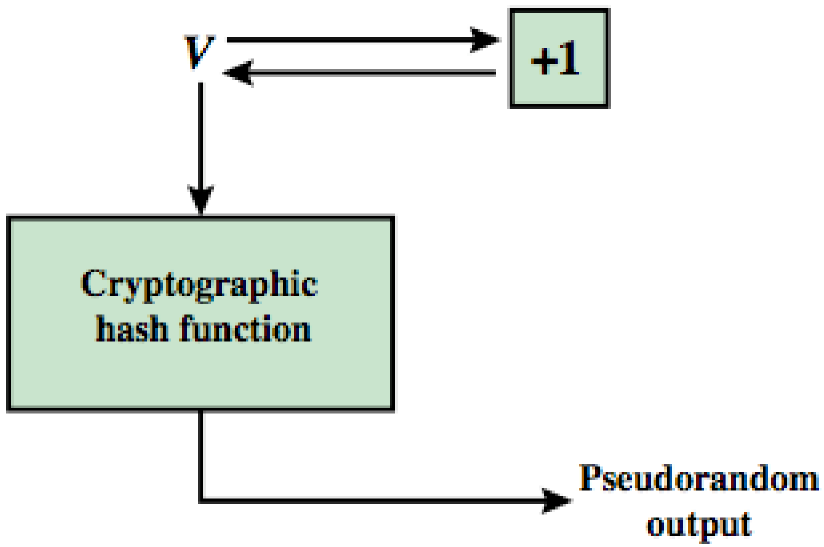
(a) $GHASH_H(X_1 \| X_2 \| \ldots \| X_m) =$ Tag

PRNG Using Hash and MACs

- Essential elements of Pseudo-Random Number generation:
  - Seed value
  - Deterministic algorithm
- Seed must be known only as needed
- PRNG can be based on
  1. Encryption algorithm
  2. Hash function (ISO18031 & NIST SP 800-90)
  3. MAC (NIST SP 800-90)

PRNG using a Hash Function

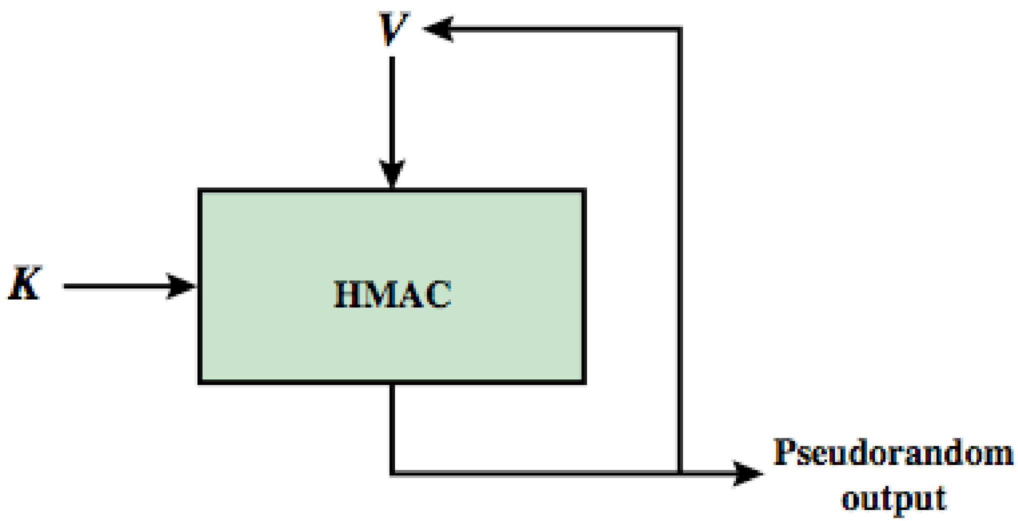
- SP800-90 and ISO18031
  - Take seed V
  - Repeatedly add 1
  - Hash V
  - Use n-bits of hash as random value
- Secure if good hash used



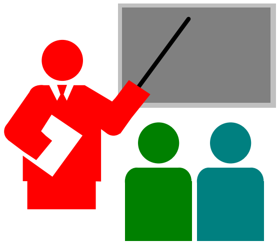
(a) PRNG using cryptographic hash function

PRNG using a MAC

- SP800-90, IEEE 802.11i, TLS
  - Use key
  - Input based on last hash in various ways



(b) PRNG using HMAC



Summary

1. Message authentication = Integrity + Source Authentication (with or without encryption)
2. Double public key encryption can be used but complex ⇒ Hash with a secret key
3. HMAC is a general procedure usable with any hash function ⇒ HMAC-MD5, HMAC-AES
4. Data Authentication Algorithm (DAA) was found insecure ⇒ Fixed by CMAC using keys derived from a single key
5. Authenticated Encryption:
    1. CCM = CMAC + Counter mode
    2. GCM = Multiplication in GF(2^{128}) + Counter mode
6. Pseudorandom Number Generation (PRNG) using Hash Functions and MACs

Homework 12

12.6 There are four general approaches in authenticated encryption: HtE, MtE, EtM, and E&M.

A. Which approach is used for CCM?

B. Which approach is used for GCM?

