UNIVERSITY OF MASSACHUSETTS
Dept. of Electrical & Computer Engineering

Introduction to Cryptography
ECE 597XX/697XX

Part 12

Message Authentication Codes (MACs)

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Adapted from Paar & Pelzl, "Understanding Cryptography," and other sources

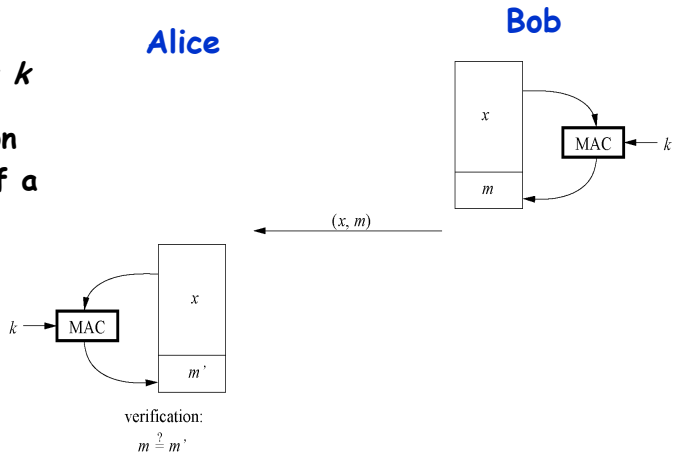
Content of this part

- The principle behind MACs
- The security properties that can be achieved with MACs
- How MACs can be realized with hash functions and with block ciphers

Adapted from Paar & Pelzl, "Understanding Cryptography," and other sources

Principle of MACs

- Similar to digital signatures, MACs append an authentication tag to a message
- MACs use a symmetric key k for generation and verification
- Computation of a MAC: $m = MAC_k(x)$



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Properties of Message Authentication Codes

1. **Cryptographic checksum**
   A MAC generates a cryptographically secure authentication tag for a given message.
2. **Symmetric**
   MACs are based on secret symmetric keys. The signing and verifying parties must share a secret key.
3. **Arbitrary message size**
   MACs accept messages of arbitrary length.
4. **Fixed output length**
   MACs generate fixed-size authentication tags.
5. **Message integrity**
   MACs provide message integrity: Any manipulations of a message during transit will be detected by the receiver.
6. **Message authentication**
   The receiving party is assured of the origin of the message.
7. **No nonrepudiation**
   Since MACs are based on symmetric principles, they do not provide nonrepudiation.

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MACs from Hash Functions

- MAC is realized with cryptographic hash functions (e.g., SHA-1)
- HMAC is such a MAC built from a hash function
- Basic idea: Key is hashed together with the message
- Two possible constructions:
  - secret prefix MAC: $m = MAC_k(x) = h(k||x)=h(k||x_1,x_2, \ldots,x_n)$
  - secret suffix MAC: $m = MAC_k(x) = h(x||k)=h(x_1,x_2, \ldots,x_n||k)$
- Attacks:
  - secret prefix MAC: Attack MAC for the message $x = (x_1,x_2, \ldots,x_n,x_{n+1})$, *where* x_{n+1} is an arbitrary additional block, can be constructed from m without knowing the secret key
  - Oscar intercepts $x = (x_1,x_2, \ldots,x_n)$ and m
  - Adds x_{n+1} and calculates $m_O = h(m||x_{n+1})$
  - Sends $(x_1,x_2, \ldots,x_n, x_{n+1})$ and m_O

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Secret suffix MAC

- $m = MAC_k(x) = h(x||k)=h(x_1,x_2, \ldots,x_n||k)$
- Attack:
  - find collision x and x_O such that $h(x) = h(x_O)$, then $m = h(x||k) = h(x_O||k)$
  - can replace x by x_O
  - for a 160-bit about 2^{80} attempts are needed

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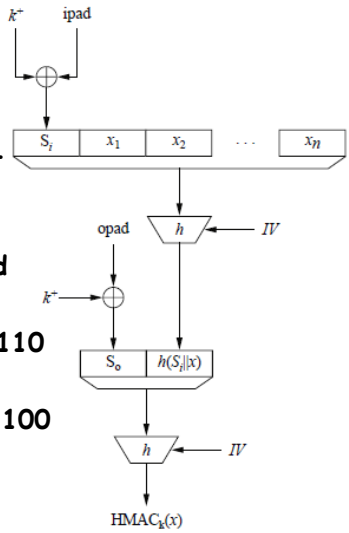
HMAC

- Proposed by Bellare, Canetti and Krawczyk in 1996
- Avoids the above security weknesses
- Scheme consists of an inner and outer hash



- k^+ is expanded key k with 0's on the left to match the size of a hash block
- expanded key k^+ is XORed with inner pad
- ipad =00110110,00110110, . . .,00110110
- opad =01011100,01011100, . . .,01011100
- $HMAC_K(x) = h[(k^+ \oplus opad)||h[(k^+ \oplus ipad)||x]]$

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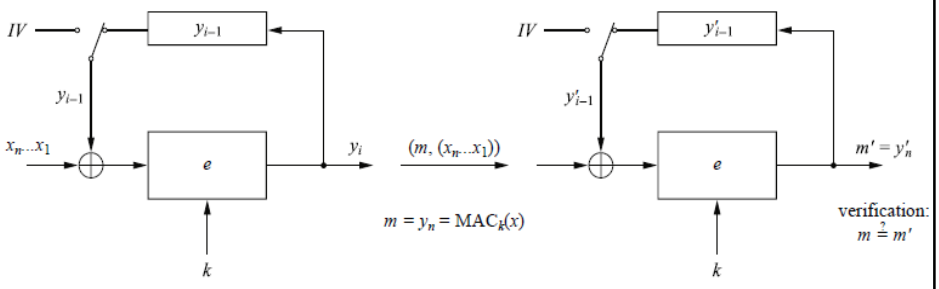
MACs from Block Ciphers

- MAC constructed from block ciphers (e.g., AES)
- Popular: Use AES in CBC (cipher block chaining) mode
- CBC-MAC:



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CBC-MAC

- MAC Generation
  - Divide the message x into blocks x_i
  - Compute first iteration $y_1 = e_K(x_1 \oplus IV)$
  - Compute $y_i = e_K(x_i \oplus y_{i-1})$ for the next blocks
  - Final block is the MAC value: $m = MAC_K(x) = y_n$
- MAC Verification
  - Repeat MAC computation (m')
  - Compare results: If $m' = m$, the message is verified as correct
  - If $m' \neq m$, the message and/or the MAC value m have been altered during transmission

Lessons Learned

- MACs provide two security services, *message integrity and message authentication, u*sing symmetric ciphers. MACs are widely used in protocols.
- Both of these services are also provided by digital signatures, but MACs are much faster.
- MACs do not provide nonrepudiation.
- In practice, MACs are either based on block ciphers or on hash functions.
- HMAC is a popular MAC used in many practical protocols such as Transport Layer Security (TLS) – indicated by a small lock in the browser.