Message Authentication Codes

CSS322: Security and Cryptography

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Attacks on Communications across Network

1. Disclosure: encryption
2. Traffic analysis: encryption
3. Masquerade: message authentication
4. Content modification: message authentication
5. Sequence modification: message authentication
6. Timing modification: message authentication
7. Source repudiation: digital signatures
8. Destination repudiation: digital signatures

Message Authentication Functions

- Message authentication (and digital signature) mechanisms have two parts:
  1. Function that produces authenticator
  2. Protocol that enables receiver to verify authenticity
- Three types of authentication functions:
  1. Hash function
  2. Message encryption
  3. Message authentication code (MAC)

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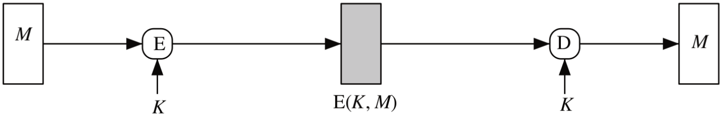
Symmetric Encryption for Authentication



- Confidentiality: only B (and A) can recover plaintext
- Source Authentication: A is only other user with key; must have come from A
- Data Authentication: successfully decrypted; data has not been modified
- Assumption: decryptor can recognise correct plaintext

Recognising Correct Plaintext

Example 1

B receives ciphertext (supposedly from A, using shared secret key K):

`DPNFCTEJLYONCJAEZRCLASJTDQFY`

B decrypts with key K to obtain plaintext:

`SECURITYANDCRYPTOGRAPHYISFUN`

- Was the plaintext encrypted with key K (and hence sent by A)?
- Is the ciphertext received the same as the ciphertext sent by A?

Recognising Correct Plaintext

Example 2

B receives ciphertext (supposedly from A, using shared secret key K):

`QEFPFPQEBTOLKDJBPPXDBPLOOVX`

B decrypts with key K to obtain plaintext:

`FTUEUEFTQIDAZSYQEEMSQEADDKM`

- Was the plaintext encrypted with key K (and hence sent by A)?
- Is the ciphertext received the same as the ciphertext sent by A?

Recognising Correct Plaintext

Example 3

B receives ciphertext (supposedly from A, using shared secret key K):

0110100110101101010110111000010

B decrypts with key K to obtain plaintext:

0101110100001101001010100101110

- Was the plaintext encrypted with key K (and hence sent by A)?
- Is the ciphertext received the same as the ciphertext sent by A?

Recognising Correct Plaintext

Example 1

- Assume the message is English
- Plaintext had expected structure; assume the plaintext is correct
  - Sent by A and has not been modified

Example 2

- Assume the message is English
- Plaintext had no structure in expected language; assume plaintext is incorrect
  - Either not sent by A or modified

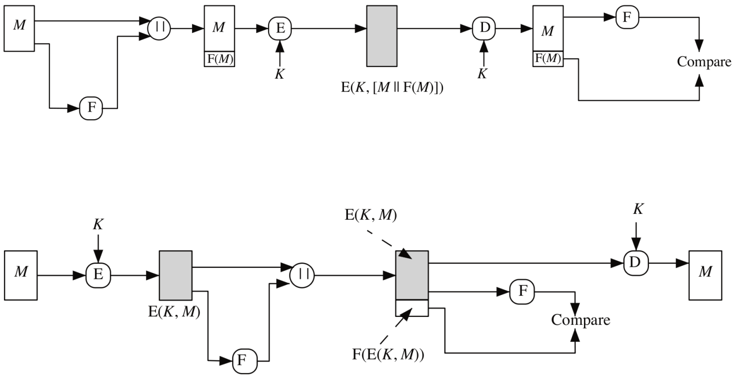
Example 3

- Binary data, e.g. image, compressed file
- Cannot know whether correct or incorrect

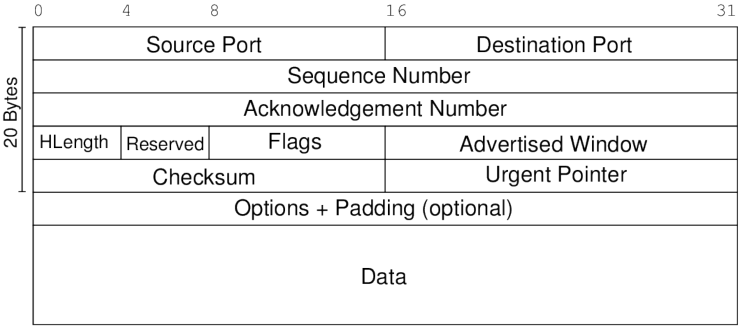
Recognising Correct Plaintext

- Valid plaintexts should be small subset of all possible messages
  - E.g. 26^n possible messages of length n; only small subset are valid English phrases
- Plaintext messages have structure
- BUT automatically detecting structure can be difficult
- Add structure to make it easier, e.g.
  - Error detecting code or Frame Check Sequence
  - Packet header

Adding Error Detecting Code

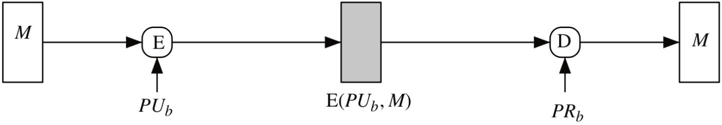


TCP Segment


0
4
8
16
31
20 Bytes
Source Port
Destination Port
Sequence Number
Acknowledgement Number
HLength
Reserved
Flags
Advertised Window
Checksum
Urgent Pointer
Options + Padding (optional)
Data

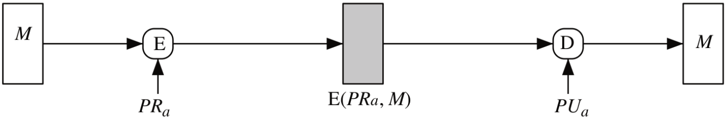
Public-Key Encryption for Authentication

- Only provides confidentiality
- Same assumption as before: plaintext must have structure so can be recognised as correct or incorrect



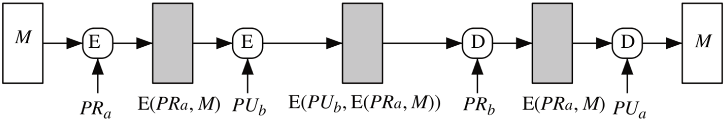
Public-Key Encryption for Authentication

- Data authentication (data has not been modified)
- Digital signature: proof that message came from A



Public-Key Encryption for Authentication

- Both confidentiality, authentication and digital signature



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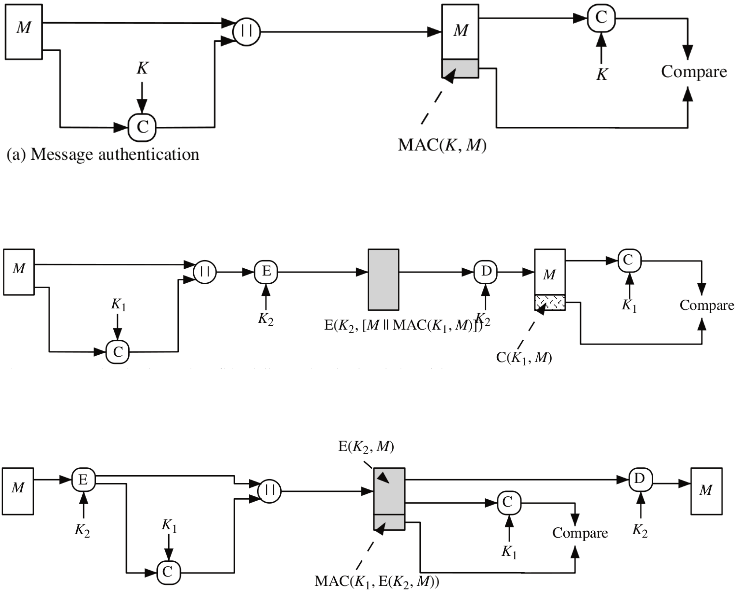
Authentication with Message Authentication Codes

- Append small, fixed-size block of data to message: cryptographic checksum or MAC

$$\mathrm{T} = \mathrm{MAC}(K, M)$$

M = input message
MAC = MAC function
K = shared secret key of k bits
T = message authentication code (or tag) of n bits

- MAC function also called *keyed hash function*
- MAC function similar to encryption, but does not need to be reversible
  - Easier to design stronger MAC functions than encryption functions


M
K
C
||
M
C
K
Compare
MAC(K, M)
(a) Message authentication
M
K1
C
||
E
K2
E(K2, [M || MAC(K1, M)])
D
K2
M
C
K1
Compare
C(K1, M)
M
E
K2
K1
C
||
E(K2, M)
MAC(K1, E(K2, M))
C
K1
Compare
D
K2
M

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Requirement of MACs

Objective of Attacker

- Assume MAC function is known, key K is not
- For valid MAC code for given message x

Requirement of MAC Function

Computation Resistance : given one or more text-MAC pairs $[x_i, MAC(K, x_i)]$, computationally infeasible to compute any text-MAC pair $[x, MAC(K, x)]$ for new input $x \neq x_i$

Security of MACs

Brute Force Attack on Key

- Attacker knows $[x_1, T_1]$ where $T_1 = MAC(K, x_1)$
- Key size of k bits: brute force on key, 2^k
- But ... many tags match T_1
- For keys that produce tag T_1, try again with $[x_2, T_2]$
- Effort to find K is approximately 2^k

Brute Force Attack on MAC value

- For x_m, find T_m without knowing K
- Similar effort required as one-way/weak collision resistant property for hash functions
- For n bit MAC value length, effort is 2^n

Effort to break MAC: $\min(2^k, 2^n)$

Security of MACs

Cryptanalysis

- Many different MAC algorithms; attacks specific to algorithms
- MAC algorithms generally considered secure

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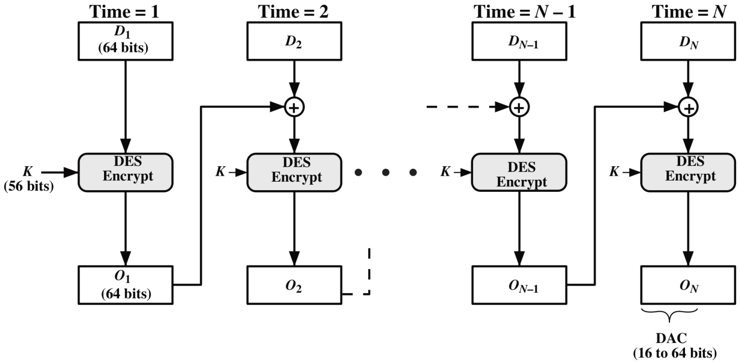
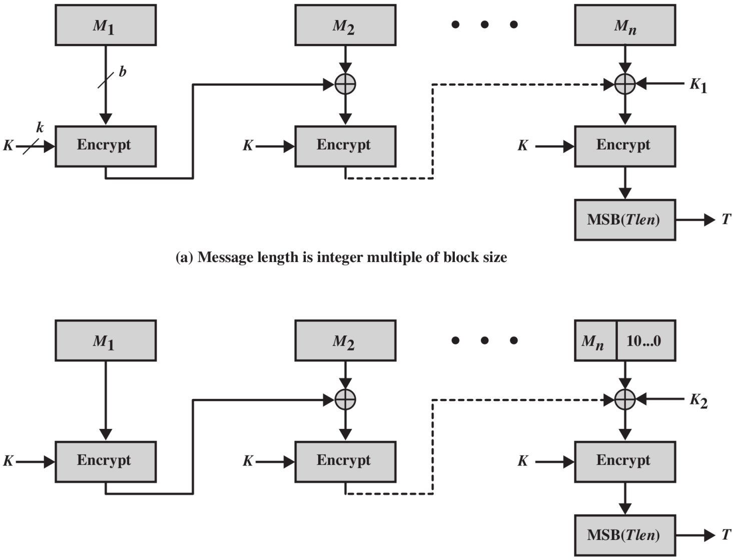
MACs Based on Block Ciphers

- Data Authentication Algorithm (DAA): based on DES; considered insecure
- Cipher-Based Message Authentication Code (CMAC): mode of operation used with Triple-DES and AES
- OMAC, PMAC, UMAC, VMAC, ...

DAA


Time = 1
D1
(64 bits)
DES Encrypt
K
(56 bits)
O1
(64 bits)
Time = 2
D2
K
DES Encrypt
O2
Time = N – 1
DN–1
K
DES Encrypt
ON–1
Time = N
DN
K
DES Encrypt
ON
DAC
(16 to 64 bits)

CMAC



(a) Message length is integer multiple of block size

(b) Message length is not integer multiple of block size

HMAC

- MAC function derived from cryptographic hash functions
  - MD5/SHA are fast in software (compared to block ciphers)
  - Libraries for hash functions widely available

$$\mathrm{HMAC}(K, M) = \mathrm{H}((K \oplus \mathrm{opad})||\mathrm{H}((K \oplus ipad)||M))$$

  where ipad= 00110110 repeated, opad= 01011100 repeated

- Security of HMAC depends on security of hash function used