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PUBLIC KEY CRYPTOGRAPHY AND MESSAGE AUTHENTICATION

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Public Key Cryptography and Message Authentication

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c) Simple Hash Functions

d) The SHA Secure Hash Function

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a) HMAC

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Public Key Cryptography and Message Authentication

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- **3.4 Public-Key Cryptography Principles**

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b) Applications for Public-Key Cryptosystems

c) Requirements for Public-Key Cryptography

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a) The RSA Public-Key Encryption Algorithm

b) Diffie-Hellman Key Exchange

c) Other Public-Key Cryptography Algorithms

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**Image credit: 123RF*

Public Key Cryptography and Message Authentication

- **3.1 Approaches to Message Authentication**

a) Authentication Using Conventional Encryption

b) Message Authentication without Message Encryption

Image Credit: 123RF

Public Key Cryptography and Message Authentication

3.1 Approaches to Message Authentication (continued)

Message authentication is a procedure that allows communicating parties to verify that received messages are **authentic***.

*Authentic: when data is **genuine** (not altered – Data Integrity) and the receiving party can verify the **source** of the **message**

Aims of Message Authentication:

- Integrity: Verify that the contents of the message have not been altered
- Validating identity of the source
- Non-repudiation: Verify timeliness and message sequence flow

Protects against active attacks (ie falsification of data and transactions)

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3.1 Approaches to Message Authentication (continued)

a)Authentication Using Conventional Encryption

- Symmetric encryption*
  - Same key to encrypt & decrypt
  - Receiver knows sender must have created it
  - Weak against**
    - block reordering
    - Unauthorised modification
  - Therefore, **not suitable** for data authentication
    - Doesn't provide Integrity
    - Doesn't provide Authentication

*Symmetric encryption covered on Chapter 2 – Page 27

**Encryption alone without other mechanisms.

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3.1 Approaches to Message Authentication (continued)

b) Message Authentication without Message Encryption

- Non-confidentiality: The message is in plain-text
- Reasons to not encrypt the message:
  - Reduce load
  - Quicker
  - Cheaper
- Several approaches:
  - Message Authentication Code
  - One-Way Hash Function

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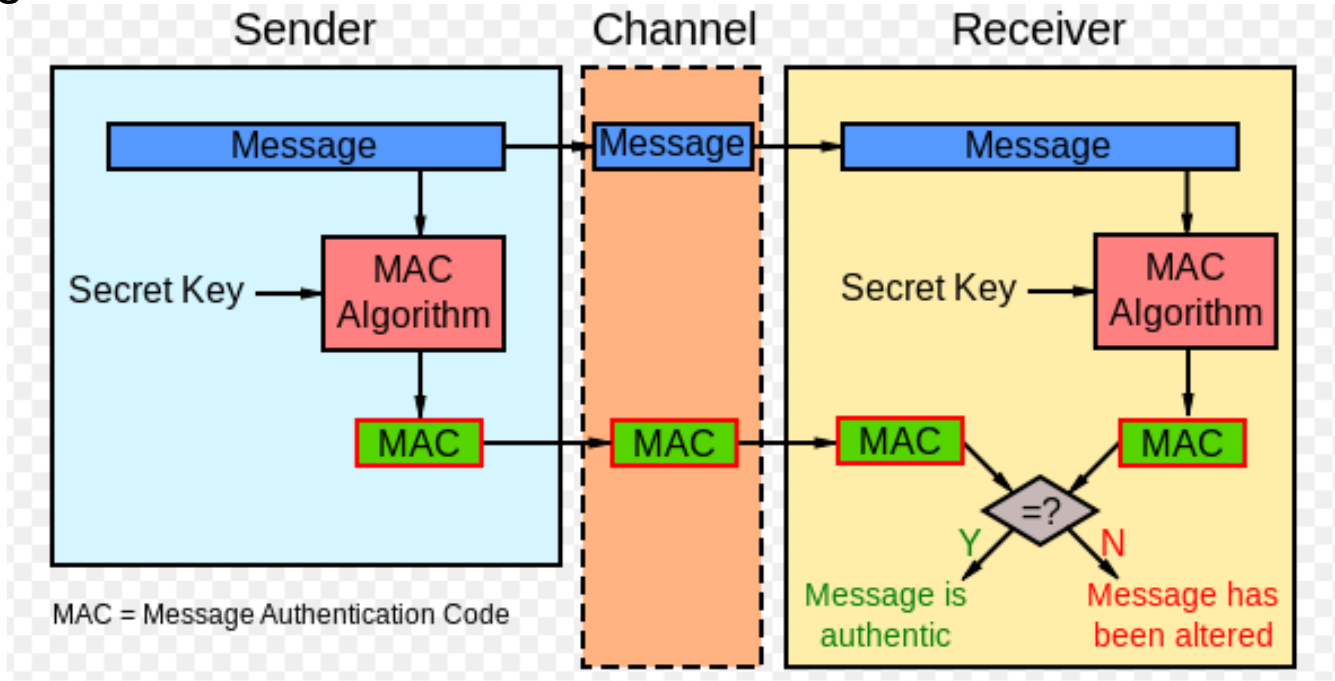
3.1 Approaches to Message Authentication (continued)

- Message Authentication Code - MAC



– Drawbacks

- Weak against brute-force – at least 128bit MAC is needed
- is a many-to-one function – potentially many messages have same MAC
- Replay attacks – unless it has time stamp, one-time MAC or sequence number

•*Image source: Public domain

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- **3.1 Approaches to Message Authentication (continued)**

- **One-Way Hash Function**
  - It takes a variable length input M and converts it into a fixed-length sequence h
    - h=H(M)
  - The process is “easy” to compute but “hard” to reverse – hence one-way*
  - Sender uses a hash function to produce a message digest
  - Sender attaches the digest to the message and forward it to the receiver
  - Receiver does same calculation and compares it with the attached digest.
    - Usually the hash function is public and not keyed (unlike MAC)
  - Used for
    - Message Authentication
    - Signatures (More on this later on)

**explained in the next chapter*

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- **3.2 Secure Hash Functions**

a) Hash Function Requirements
b) Security of Hash Functions
c) Simple Hash Functions
d) The SHA Secure Hash Function

Image Credit: Foto Search

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3.2 Secure Hash Functions (continued)

a) Hash Function Requirements

•Purpose:

– To produce a message digest (aka hash value or fingerprint) of a file/message/data

•Requirements of hash function - H:

1. can be applied to any sized message M
2. produces a fixed-length output – message digest h
3. is easy to compute h=H(M) for any message
4. Preimage resistant / One way: Knowing h is infeasible to find out x - H(x)=h
5. Second preimage resistant / Weak collision resistant: given x is infeasible to find y H(y)=H(x)
6. (Strong) collision resistance: is infeasible to find any x,y

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3.2 Secure Hash Functions (continued)

- Collision

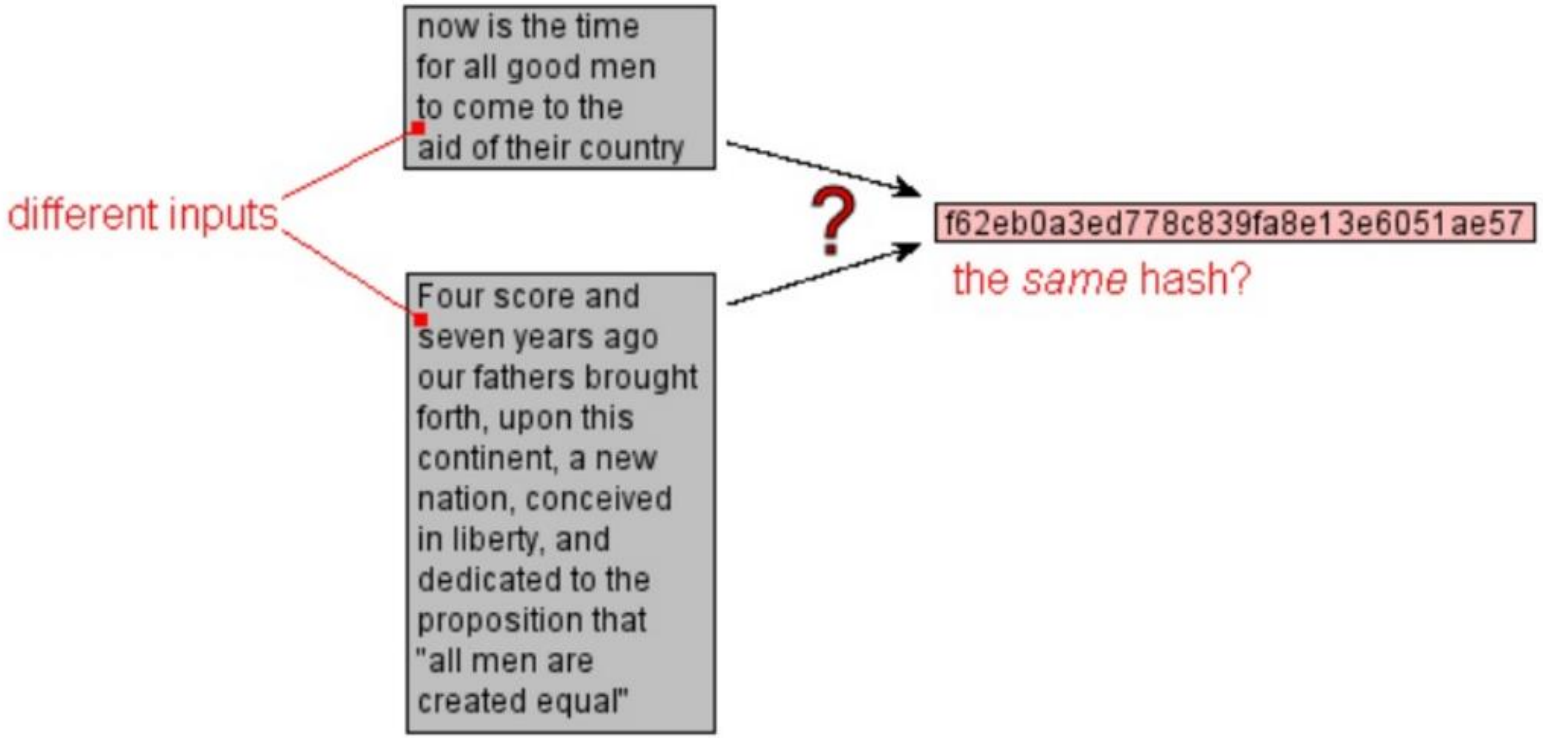

**Image credit: Sikder University of Science and Technology (Bangladesh)*

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3.2 Secure Hash Functions (continued)

b) Security of Hash Function

•Attacks:

- Brute-force
  - The level of effort depends on:

    -Length of the hash code produced.

- Cryptanalysis
  - The level of effort depends on:

    -The logical weakness in the algorithm

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3.2 Secure Hash Functions (continued)

c) Simple Hash Function

–Principles:

- The input is viewed as a sequence of n-bit blocks
- The input is processed one block at a time to produce a n-bit hash function

- Bit-by-bit exclusive OR (XOR)
  - Bitwise operator
  - The message is encrypted with a randomly generated string – secret key
  - This random secret key (ideally one–time pad) should be as long as the message and produces a ciphertext

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3.2 Secure Hash Functions (continued)

- **XOR**
  - Example

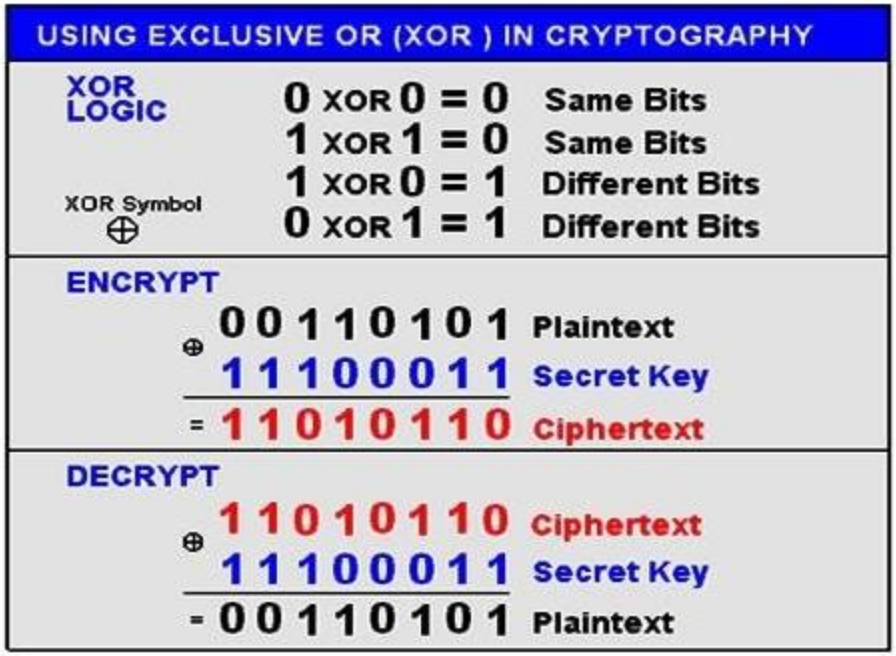

**Image Credit: wonderhowto.com*

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3.2 Secure Hash Functions (continued)

- **XOR**
  - Advantages
    - Simple to implement
    - Computationally inexpensive
  - Drawbacks
    - Impractical to have a key as long as the message
    - Not secure by itself alone (linear elements can easily be broken, given a few known plaintext - cipher text pairs, it is possible to recover the key)

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3.2 Secure Hash Functions (continued)

- **Secure Hash Function SHA**
  - Based on MD4
  - Most popular hash
  - SHA-1 - hash value 160bit (Deprecated since 2010 ie: *SSL certificates signed with SHA-1 will not be accepted by Microsoft and Google during 2016 and after)*
  - SHA-2 - hash value 256, 384 or 512bit
  - SHA-3 – hash value 256, 384 or 512bit (internal structure differs significantly from rest of SHA). Standardised 2015

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3.2 Secure Hash Functions (continued)

- **Secure Hash Function SHA**
  - Overview (SHA-2)

1. Pad message so its length is 896 and mod 1024
2. Append a 128-bit length value to message
3. Initialise 512-bit hash buffer

   Initial values:

$a = 6A09E667F3BCC908$ $e = 510E527FADE682D1$

$b = BB67AE8584CAA73B$ $f = 9B05688C2B3E6C1F$

$c = 3C6EF372FE94F82B$ $g = 1F83D9ABFB41BD6B$

$d = A54FF53A5F1D36F1$ $h = 5BE0CD19137E2179$

4. Process message in 128-word (1024-bit) chunks

   -Take initial input of hash buffer and update the content

   -Perform set of functions

   -Update hash buffer

5. Output has value is the final buffer value

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- **3.3 Message Authentication Codes**

a) HMAC

b) MACs Based on Block Ciphers

Image Credit: Care Realism

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3.3 Message Authentication Codes (continued)

- **a) HMAC**
  - Main idea is to have a MAC derived from a hash code (eg SHA-1)
    - Hash are quicker to execute compared to conventional encryption algorithm
    - Library code for hash functions widely available
- HMAC Design Objectives
  - Use free, available hash functions
  - Make it easy to replace hash functions
  - No performance degradation
  - Simple key management
  - Embedded hash function should be strong

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3.3 Message Authentication Codes (continued)

- HMAC Algorithm

$$HMAC(K, m) = H\left((K \oplus opad) \;||\; H\left((K \oplus ipad) \;||\; m\right)\right)$$

  - H hash function - any of MD5, SHA-1, RIPEMD-160 can be used
  - K is the key padded out to size
  - m is the message
  - and opad, ipad* are specified padding constants

- HMAC Security
  - The security depends on the hash used
  - Attacks:
    - Brute-force on key used
    - Birthday attack

**ipad = the byte 0x36 repeated B times*
opad = the byte 0x5C repeated B times

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3.3 Message Authentication Codes (continued)

- **b) MACs Based on Block Ciphers**
  - Block ciphers encrypt the data as a whole rather than bit by bit
  - Types:
    - Cipher-Based Message Authentication Code - CMAC
    - Counter with Cipher Block Chaining-Message Authentication Code – CCM
  - Cipher-Based Message Authentication Code – CMAC
    - *"New"* method - 2006
    - Calculates message authentication codes using a block cipher coupled with a secret key
    - Uses AES and triple DES
    - Useful when a block cipher is preferred instead of a hash function
    - Block ciphers usually slower than hash functions

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3.3 Message Authentication Codes (continued)

- Counter Mode with Cipher Block Chaining-Message Authentication Code
  - aka CCM or Counter with CBC-MAC
    - Considered an Authentication Encryption mode
    - “Authenticate-then-encrypt” concept
    - Single key is used for encryption and MAC algorithm
    - Used on Wireless LAN (IEEE 802.11i standard – WPA2)

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- **3.4 Public-Key Cryptography Principles**

a) Public-Key Encryption Structure
b) Applications for Public-Key Cryptosystems
c) Requirements for Public-Key Cryptography

Image Credit: Deposit Photos

Public Key Cryptography and Message Authentication

3.4 Public-Key Cryptography Principles (continued)

- **a) Public-Key Encryption Structure**
  - Asymmetric – Uses 2 keys
  - Components
    - Plain-text
    - Encryption algorithm
    - Private & Public Key
    - Cipher-text
    - Decryption algorithm

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3.4 Public-Key Cryptography Principles (continued)

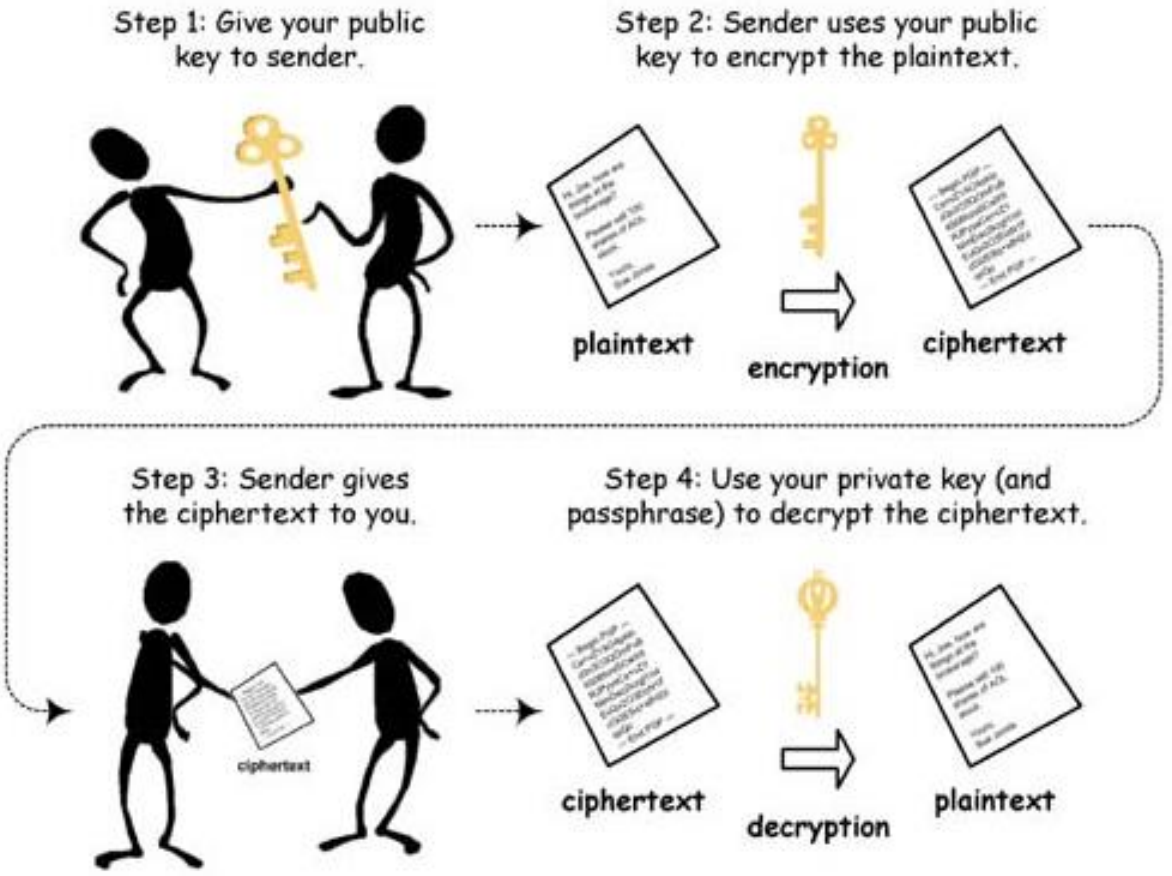

**Image credit: University of Illinois at Chicago - https://www.uic.edu/depts/accc/newsletter/adn26/figure2.html*

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3.4 Public-Key Cryptography Principles (continued)

- **b) Applications for Public-Key Cryptosystems**
  - Encryption/Decryption
  - Digital Signature (More later on – chap. 3.6)
  - Key Exchange
- **c) Requirements for Public-Key Cryptography**
  - Easy to generate pair of keys
  - Easy for the sender to encrypt message with public key
  - Easy to receiver to decrypt message with private key
  - Infeasible to determine the private key with the public key
  - Infeasible to recover the message without private key
  - Both keys can either be used to encrypt or decrypt.

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- **3.5 Public-Key Cryptography Algorithms**

a) The RSA Public-Key Encryption Algorithm
b) Diffie-Hellman Key Exchange
c) Other Public-Key Cryptography Algorithms

Image Credit: 123RF

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3.5 Public-Key Cryptography Algorithms (continued)

- **a) The RSA Public-Key Encryption Algorithm**
  - Widely used for encryption (eg SSH, TLS) and digital signatures
  - Security based on the difficulty of factoring* large integers that are product of two large prime numbers.
  - Minimum recommended key length 1024-bit
  - How to defeat it
    - Brute force
    - Factoring

**Finding what to multiply together to get an expression.*

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3.5 Public-Key Cryptography Algorithms (continued)

- Algorithm
  - Select random prime numbers *p* and *q*, and check that $p \neq q$
  - Compute modulus $n = pq$
  - Compute phi, $\Phi = (p - 1)(q - 1)$
  - Select public exponent *e*, $1 < e < \Phi$ such that $gcd(e, \Phi) = 1$
  - Compute private exponent $d = e^{-1} \bmod \Phi$
  - Public key is $\{n, e\}$, private key is *d*
- Example
  1. Select primes: $p=17$ & $q=11$
  2. Compute $n = pq = 17 \times 11 = 187$
  3. Compute $\phi(n) = (p-1)(q-1) = 16 \times 10 = 160$
  4. Select e : $\gcd(e,160)=1$; choose $e=7$
  5. Determine d: $de=1 \bmod 160$ and $d < 160$
     Value is $d=23$ since $23 \times 7 = 161 = 10 \times 160 + 1$
  6. Publish public key $KU=\{7,187\}$
  7. Keep secret private key $KR=\{23,17,11\}$

**Example credit: Yonsei University*

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3.5 Public-Key Cryptography Algorithms (continued)

- **b) Diffie-Hellman Key Exchange**
  - Use to exchange keys securely
  - Security based on difficulty of computing discrete logarithms*
  - Steps
    - 1. Alice and Bob agree on a prime number p and a base g.
    - 2. Alice chooses a secret number a, and sends Bob (g a mod p).
    - 3. Bob chooses a secret number b, and sends Alice (g b mod p).
    - 4. Alice computes ((g b mod p) a mod p).
    - 5. Bob computes ((g a mod p) b mod p).

    Both Alice and Bob can use this number as their key.

    Note that p and g need not be protected.

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- **Example**
  - Alice and Bob agree on p = 23 and g = 5
  - Alice chooses a = 6 and sends 5^6 mod 23 = 8
  - Bob chooses b = 15 and sends 5^{15} mod 23 = 19
  - Alice computes 19^6 mod 23 = 2
  - Bob computes 8^{15} mod 23 = 2

Discovering the shared secret given g, p, g a mod p and g b mod p would take longer than the lifetime of the universe, using the best known algorithm. This is called the discrete logarithm problem

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3.5 Public-Key Cryptography Algorithms (continued)

- How to beat Diffie-Hellman
  - Brute-force: Infeasible with large prime numbers
  - Man-in-the-Middle: Algorithm does NOT authenticate

Public Key Cryptography and Message Authentication

3.5 Public-Key Cryptography Algorithms (continued)

c) Other Public-Key Cryptography Algorithms

– Elliptic-Curve Cryptography - ECC

- Uses smaller keys compared to RSA with equal security
- Quicker
- Used on low computational devices

– Digital Signature Standard – DSS

- Provides only digital signature function
- No encryption
- Cannot be used for key exchange
- US government standard for authentication of electronic documents

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- **3.6 Digital Signatures**

Image Credit: Dreams Time

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3.6 Digital Signatures (continued)

- At a glance:
  - Alice creates a digital signature with her private key
  - The signature is attached to the message
  - Bob uses Alices's public key to verify the signature
  - The whole message might or not be encrypted (usually no)

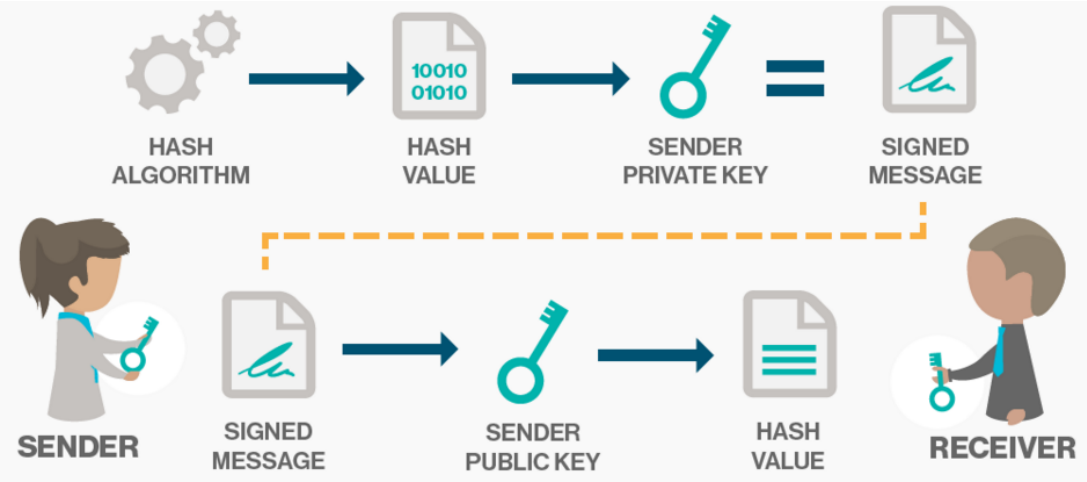

Image credit: SearchTarget.com

Public Key Cryptography and Message Authentication

3.6 Digital Signatures (continued)

- Properties:
  - Provides Integrity
  - Provides Authentication
  - Provides Non-repudiation
  - Does NOT provide confidentiality

Public Key Cryptography and Message Authentication

- **Resume**
  - **Message Authentication**
    - Symmetric encryption – not suitable for Message Authentication
    - Hash functions – XOR & SHA
    - MAC
      - HMAC
      - MAC Based on Block Ciphers
  - **Public-Key Encryption**
    - RSA
    - Diffie-Hellman
    - Elliptic-Curve Cryptography & Digital Signature Standard
  - **Digital Signatures**

Image Credit: Ris EU

Q & A

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