Cryptography and Network Security
Digital Signature

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Message Authentication Digital Signature

- Authentication
  - Authentication requirements
  - Authentication functions
- Mechanisms
  - MAC: message authentication code
  - Hash functions, security in hash functions
  - Hash and MAC algorithms
    - MD5, SHA, RIPEMD-160, HMAC
- Digital signatures

Message Attacks

- Possible attacks
  - Disclosure
  - Traffic analysis
  - Masquerade
  - Content modification
  - Sequence modification
  - Time modification
  - Repudiation
    - Denial of the receipt of message by the destination or
    - Denial of the transmitting by the source

Authentication

- Enables receiver to verify message authenticity
  - Using some lower level functions as primitive
- Three types of functions
  - Message encryption
  - Message authentication code
  - Hash function

Message Encryption

- Conventional Encryption
  - Authentication provided due to the secret key
  - But the message need to be meaningful
    - What happened it message is not readable?
    - How to determine intelligible automatically?
- Approach
  - Checksum or frame check sequence(FCS) to message
  - Encrypt the message and the appending FCS
  - Receiver decrypt the ciphertext
  - Computes FCS of message, compare with received one

Public Key Encryption

- Direct encryption by receiver's public key
  - Only confidentiality, no authentication
- For authentication
  - Encrypt using sender's private key
  - Assume the message is intelligible
  - No confidentiality: everyone can decrypt
- Confidentiality and authentication
  - Encrypt by sender's, then receiver's public key
  - But too time-consuming: 4 rounds RSA on large data

Message Authentication Code

- Assume both uses share secret key k
- Procedure
  - Sender computes MAC=$C_k(M)$ for M
  - Sent M and MAC of it to receiver
  - Receiver computes the MAC on received M
  - Compare it with received MAC
  - If match, then accepts the message
- MAC is similar to encryption, but not need be reversible!

MAC with Confidentiality

- Two options
  - Using another key to encrypt M and MAC
  - Using another key to encrypt M only
- Requirements of MAC
  - Size of MAC: n
  - Size of key: k
  - Need 2^n computations of MAC and n/k pairs of M_i and MAC_i

Why not Conventional Encrypt

- Possible situations
  - Broadcast a message (one destination can verify)
  - Authentication is done selectively
  - Authentication of computer program
  - Authentication may be important than secrecy
  - Architecture flexibility
  - Authentication lasts longer than secret protection

MAC Requirements

- Computationally infeasible to construct M' such that $C_k(M')=C_k(M)$
- $C_k(M)$ uniformly distributed

Data Authentication Algorithm

- ANSI standard X9.17
- Based on DES
- Using Cipher Block Chaining mode
  - Data is grouped into 64 bits blocks
    - Padding 0's if necessary
  - $Output_i=E_k(D_i ? Output_{i-1})$
    - 0<i, and $Output_0$=0's
  - The data authentication code DAC consists of the leftmost m bits of the last output, m?16

Hash Function

- Map a message to a smaller value
- Requirements
  - Be applied to a block of data of any size
  - Produced a fixed length output
  - H(x) is easy to compute (by hardware, software)
  - **One-way**: given code h, it is computationally infeasible to find x: H(x)=h
  - **Weak collision resistance**: given x, computationally infeasible to find y so H(x)=H(y)
  - **Strong collision resistance**: Computationally infeasible to find x, y so H(x)=H(y)

Basic Uses of Hash Function

- Six basics usages
  - $E_k(M||H(M))$
    - Confidentiality and authentication
  - $M|| E_k(H(M))$
    - Authentication
  - $M|| E_{KRa}(H(M))$
    - Authentication and digital signature
  - $E_k(M|| E_{KRa}(H(M)))$
    - Authentication, digital signature and confidentiality
  - $M||H(M||S)$
    - Authentication (S shared by both sides)
  - $E_k(M||H(M||S))$
    - Confidentiality and authentication

Birthday Attacks

- If 64-bits hash code is used
  - On average, how many messages need to try to find one match the intercepted hash code?
- Birthday paradox
  - A will sign a message appended with m-bits hash code
  - Attacker generates some variations of fraud message, also variations of good message
  - Find pair of message each from the two sets messages
    - Such that they have the same hash code
  - Give good message to A to get signature
  - Replace good message with fraud message

Analysis

- Using birthday attack, given 64-bits hash code
  - How many message variations needed so the success probability is large, say 90%?

Examples

- Simple hash functions
  - XOR of the input message
    - $H(M)=X_1$? X_2? …? X_{m-1}? X_m
  - But not secure
    - $Y_m=H(M)$? Y_1? Y_2? …? Y_{m-1} has same hash value as $(X_1X_2 \ldots X_{m-1} X_m)$, where Y_i is any value

Cont.

- Based on DES, block chaining technique
  - Rabin, 1978
  - Divide message M into fix-sized blocks M_i
    - Assume total n data blocks
  - H_0=initial value
  - $H_i=E_{m_i}[H_{i-1}]$
  - H_n is the hash value
- Birthday attack still applies
  - If still 64-bits code used

More Attacks

- Birthday attack applied if chosen plaintext
- Meet in the middle attack if known plaintext
  - Known signed hash code G
  - Construct n-2 desired message block Q_i
  - Compute $H_i=E_{Q_i}[H_{i-1}]$
  - Generate $2^{m/2}$ random blocks X
    - For each X, Compute $H_{n-1}=E_X[H_{n-2}]$
  - Generate $2^{m/2}$ random blocks Y
    - For each Y, Compute $H'_{n-1}=D_Y[G]$
  - Find X, Y such that $H_{n-1}= H'_{n-1}$
  - Then $Q_1, Q_2,\ldots Q_{n-2}$, X,Y is a fraud message

Security

- The size of hash code determines security
  - 128bits is not secure
  - Currently, most use 160 bits hash code
- Attack MAC
  - Object find valid (x, $C_k(x)$) pair
  - Attack the key space: roughly 2^k, k =key size
  - Attack the MAC value

More Hash Algorithms

- Algorithms
  - Message Digest:MD5 (was mostly widely used)
  - Secure Hash Algorithm: SHA-1 (from MD4)
  - RIPEMD-160
  - HMAC

Digital Signatures

- Authentication
  - Protects two parties from the third party
  - But not protect against each other
- Digital signature
  - Verification of the message source
  - Protects the authority from anyone

Requirements

- Requirement lists
  - Signature depends on the message
  - Signature uses information unique to the signer
  - Relatively easy to sign
  - Relatively easy to recognize and verify it
  - Computationally infeasible to forge signature
    - New messages using old signature
    - Create signature for a given message
  - Practical to retain a copy of the signature for later verfication

Digital Signature Standard

- FIPS PUB 186 by NIST
- It uses
  - Secure Hashing Algorithm (SHA) for hashing
  - Digital Signature Algorithm (DSA) for signature
  - The hash code is set as input of DSA
  - The signature consists of two numbers
- DSA
  - Based on the difficulty of discrete logarithm
  - Based on Elgamal and Schnorr system

DSA

- Global public components
  - Prime number p with 512-1024 bits
  - Prime divisor q of $(p-1)$ with 160 bits
  - Integer $g=h^{(p-1)/q} \bmod p$
- Users private key
  - Random integer x less than q
- Users public key
  - Integer $y=g^x \bmod p$

DSA

- Signature
  - For each message M, generates random k
  - Computes $r=(g^k \bmod p) \bmod q$
  - Computes $s=k^{-1}(H(M)+xr) \bmod q$
  - Signature is (r,s)
- Verifying
  - Computes $w=s^{-1} \bmod q$, $u_1=H(M)w \bmod q$
  - Computes $u_2=rw \bmod q$, $v=(g^{u_1}y^{u_2} \bmod p) \bmod q$
  - Test if v=r

Proof of Correctness

- Notice that $v=(g^{u_1}y^{u_2} \bmod p) \bmod q$
  - $=(g^{H(M)w \bmod q}\, y^{rw \bmod q} \bmod p) \bmod q$
  - $=(g^{H(M)w \bmod q}\, g^{xrw \bmod q} \bmod p) \bmod q$
  - $=(g^{H(M)w + xrw \bmod q} \bmod p) \bmod q$
  - $=(g^{(H(M)+xr)w \bmod q} \bmod p) \bmod q$
  - $=(g^{(H(M)+xr)k(H(M)+xr)^{-1} \bmod q} \bmod p) \bmod q$
  - $=(g^k \bmod p) \bmod q$
  - $=r$

ElGamal Signature

- Global public components
  - Prime number p with 512-1024 bits
  - Primitive element g in Z_p
- Users private key
  - Random integer x less than p
- Users public key
  - Integer $y=g^x \bmod p$

Elgamal

- Signature
  - For each message M, generates random k
  - Computes $r=g^k \bmod p$
  - Computes $s=k^{-1}(H(M)-xr) \bmod (p-1)$
  - Signature is (r,s)
- Verifying
  - Computes $v_1=g^{H(M)} \bmod p$
  - Computes $v_2=y^r r^s \bmod p$
  - Test if $v_1=v_2$

Proof of Correctness

- Computes $v_2=y^r r^s \bmod q$
  - So $v_2=y^r r^s \bmod q = g^{xr} g^{ks} \bmod p$
  - $= g^{xr+k k^{-1}(H(M)-xr) \bmod (p-1)} \bmod p$
  - $=g^{H(M)} \bmod p = v_1$
  - Notice that here it uses Fermat theorem to show
    - That $g^{(H(M)-xr) \bmod (p-1)} \bmod p = g^{(H(M)-xr)} \bmod p$

Non-deterministic

- Non-determined signatures
  - For each message, many valid signatures exist
  - DSA, Elgamal
- Deterministic signatures
  - For each message, one valid signature exists
  - RSA

Comparisons

- Speed
  - DSS has faster signing than verifying
  - RSA could have faster verifying than signing
  - Message be signed once, but verified many times
    - This prefers the faster verification
  - But the signer may have limited computing power
    - Example: smart card
    - This prefers the faster siging

Authentication Protocols

- Central issues
  - Confidentiality: prevent masqueraded and compromised
  - Timeliness: prevent replay attacks
    - Simple replay, repetition within timestamp, replay arrives but not the true messages,backward replay attack to the sender
- Mutual authentication
- One-way authentication

Coping with Replay

- Time stamps
  - Party A accepts a message only if has valid timestamp within a valid time
  - Need synchronized clock
  - How to set the synchronized clock?
    - Network delay consideration?
- Challenge/response
  - Party A, (receiver), sends B a nonce (challenge) and requires the subsequent message contains it

Challenge-Response

- To ensure a password is never sent in the clear. Given a client and a server share a key
  - server sends a random challenge vector
  - client encrypts it with private key and returns this
  - server verifies response with copy of private key
  - can repeat protocol in other direction to authenticate server to client (2-way authentication)
- Secret key management
  - physically distributed before secure communications
  - keys are stored in a central trusted key server

Conventional Encryption App.

- Each user shares a secret master key with KDC (Key Distribution Center)
  - Kerberos is an example
  - Needham-Schroeder protocol
  - Party A ✍ KDC Ida|Idb|Na
  - KDC ✍ A E_{ka}(Ks|Idb|Na|E_{kb}(Ks|Ida))
  - A ✍ B E_{kb}(Ks|Ida)
  - B ✍ A E_{ks}(Nb)
  - A ✍ B E_{ks}(f(Nb))

Weakness

- Step 4 and 5 prevent the replay of step 3
  - Assume that Ks is not compromised
- If Ks is compromised
  - Vulnerable to replay attack
  - Attacker can replay step 3
  - Unless B remembers all previous session keys with A, it can not tell that it is a replay!

Denning Protocol

- Denning Protocol
  - Party A → KDC   Ida|Idb
  - KDC → A $E_{ka}(Ks|Idb|T|E_{kb}(Ks|Ida|T))$
  - A → B $E_{kb}(Ks|Ida|T)$
  - B → A $E_{ks}(Nb)$
  - A → B $E_{ks}(f(Nb))$
- Here T is timestamp assures the freshness of the key Ks
  - Rely on synchronized clock

Public-key Encryption App.

- The simple one proposed by Denning
  - AS: authentication server
  - A → AS   Ida|Idb
  - AS → A $E_{kr_{as}}(KUa|Ida|T)|E_{kr_{as}}(Kub|Idb|T)$
  - A → B $E_{kr_{as}}(KUa|Ida|T)|E_{kr_{as}}(Kub|Idb|T)|$
  - $E_{kub}(E_{kra}(Ks|T))$
  - It needs clock synchronization

Cont.

- Protocol by Woo and Lam, using nonce
  - A → KDC   Idа|Idb
  - KDC → A $E_{KRau}(Idb|KUb)$
  - A → B $E_{KUb}(Na|Ida)$
  - B → KDC $Idb|Ida|E_{KUau}(Na)$
  - KDC → B $E_{KRau}(Ida|KUa)|E_{KUb}(E_{kRau}(Na|Ks|Ida|Idb))$
  - B → A $E_{KUa}(E_{kRau}(Na|Ks|Ida|Idb) \mid Nb)$
  - A → B $E_{ks}(Nb)$

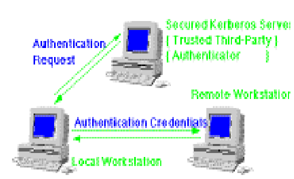
One-way Authentication

- Using Public Key approach
  - If confidentiality is main concern
    - A → B: $E_{KUb}(Ks) \mid E_{ks}(M)$
  - If authentication is main concern
    - A → B: $M|E_{KRa}(H(M))$
    - This can not avoid the interception and replay attack
  - Sign the message then
    - $E_{KUb}(M|E_{KRa}(H(M)))$
    - Or $E_{KUb}(Ks) \mid E_{ks}(M| E_{KRa}(H(M)))$
    - Also A can sends the digital certificate $E_{KRau}(T|Ida|KUa)$

Kerberos

- Trusted key server system developed by MIT
  - Provides centralized third-party authentication in a distributed network
  - access control may be provided for
    - each computing resource
    - in either a local or remote network (realm)
  - A Key Distribution Centre (KDC), containing database:
    - principles (customers and services)
    - encryption keys
  - KDC provides non-corruptible authentication credentials (tickets or tokens)

Basic Model

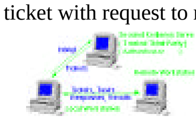


Kerberos

- Initial User Authentication
  - User requests an initial ticket from KDC used as basis for all remote access requests

Kerberos

- Request for a Remote Service
  - User requests access to a remote service
  - Obtains a ticket from KDC protected with remote key
  - Sends ticket with request to remote server



Kerberos

- Two Kerberos versions
  - 4 : restricted to a single realm
  - 5 : allows inter-realm authentication, in beta test
  - Kerberos v5 is an Internet standard specified in RFC1510
- To use Kerberos
  - need to have a KDC on your network
  - need to have Kerberised applications running on all participating systems
- US export restrictions
  - Cannot be directly distributed outside US in source format
  - Crypto libraries must be re-implemented locally

X.509 Authentication Service

- Public key certificate associated with user
  - The certificates are created by Trusted Authority
  - Then placed in the directory by TA or user
  - Itself is not responsible for creating certificate
  - It includes
    - Version, serial number, signature algorithm identifier, Issuer name, issuer identifier, validity period, the user, user identifier, user's public key, extensions, signature by TA
  - The signature by TA guarantees the authority
  - Certificates can be used to certify other Tas
  - Y<<X>>: certificate of user X issued by TA Y

Certificate Revocation

- Need the private key together with the certificate to revoke it
- The revocation is recorded at the directory
- Each time a certificate is arrived, check the directory to see if it is revoked

Identification

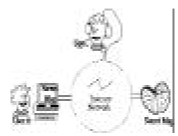
- Identification: user authentication
  - convince system of your identity
  - before it can act on your behalf
  - sometimes also require that the computer verify its identity with the user
- Based on three methods
  - what you know
  - what you have
  - what you are
- Verification
  - Validation of information supplied against a table of possible values based on users claimed identity

What you Know

- Passwords or Pass-phrases
  - prompt user for a login name and password
  - verify identity by checking that password is correct
  - on some (older) systems, password was stored clear
  - more often use a one-way function, whose output cannot easily be used to find the input value
  - either takes a fixed sized input (eg 8 chars)
  - or based on a hash function to accept a variable sized input to create the value
  - important that passwords are selected with care to reduce risk of exhaustive search

Weakness

- Traditional password scheme is vulnerable to eavesdropping over an insecure network



Solutions?

- One-time password
  - these are passwords used once only
  - future values cannot be predicted from older values
- Password generation
  - either generate a printed list, and keep matching list on system to be accessed
  - or use an algorithm based on a one-way function *f* (eg MD5) to generate previous values in series (eg SKey)
    - start with a secret password s, and number N , $p_0 = f^N(s)$
    - *i*th password in series is $p_i = f^{N-i}(s)$
  - must reset password after N uses

What you Have

- Magnetic Card, Magnetic Key
  - possess item with required code value encoded
- Smart Card or Calculator
  - may interact with system
  - may require information from user
  - could be used to actively calculate:
  - a time dependent password
  - a one-shot password
  - a challenge-response verification
  - public-key based verification

What you Are

- Verify identity based on your physical characteristics, known as biometrics
- Characteristics used include:
  - Signature (usually dynamic)
  - Fingerprint, hand geometry
  - face or body profile
  - Speech, retina pattern
- Tradeoff between
  - false rejection (type I error)
  - false acceptance (type II error)