Digital Signatures, Public Key Certificates, X509

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Digital Signatures: The Problem

- Real-life examples for signatures:
  - A person pays by credit card and signs a bill; the seller verifies that the signature on the bill is the same with the signature on the card
  - Contracts: are valid if they are signed.
- Can we have a similar service in the electronic world?

Digital Signatures

- Digital Signature: a data string which associates a message with some originating entity.
- Digital Signature Scheme:
  - a signing algorithm: takes a message and a (private) signing key, outputs a signature
  - a verification algorithm: takes a (public) key verification key, a message, and a signature
- Provides:
  - Authentication
  - Data integrity
  - Non-Repudiation

Digital Signatures and Hash

- Digital signatures are generally used with hash functions, hash of a message is signed, instead of the message.
  - Since public key encryption is costly, signing hash digest is more efficient than signing the whole message.
  - So, a digital signature generally uses
    - A hash function: MD5, SHA-1, RIPEMD
    - A public key encryption algorithm: RSA, El-gamal

RSA Signatures

Key generation (as in RSA encryption):

- Select 2 large prime numbers of about the same size, p and q
- Compute $n = pq$, and $\varphi(n) = (q - 1)(p - 1)$
- Select a random integer e, $1 < e < \varphi$, s.t. $\gcd(e, \varphi(n)) = 1$
- Compute d, $1<d<\varphi(n)$, such that $ed \equiv 1 \pmod{\varphi(n)}$

Public key: (e, n)
Secret key: d

RSA Signatures (cont.)

Signing message M

- Verify $0 < M < n$
- Compute $C = M^d \bmod n$

Verifying signature S

- Use public key (e, n)
- Compute $C^e \bmod n = (M^d \bmod n)^e \bmod n = M$

Note: In practice, a hash of the message is signed and not the message itself.

Public Keys and Trust

ALICE
Public Key: P_A
Secret key: S_A

BOB
Public Key: P_B
Secret key: S_B

- How are public keys stored?
- How to obtain the public key?
- How does Bob know or 'trusts' that P_A is Alice's public key?

Distribution of Public Keys

- Public announcement: users distribute public keys to recipients or broadcast to community at large
  - For example, put the public key to your web site
  - How to ensure the announcement is not forged by an adversary?
- Publicly available directory: can obtain greater security by registering keys with a public directory
  - How to implement the directory?

Public-Key Certificates

- A public key certificate binds identity to public key.
- Certificates are issued and signed by an entity called public key or certification authority (CA).
- Certificates can be verified by anyone who knows CA's public-key.
- CA's private key remains secret
- CA's certificate must be accessible.
- Certificates allow key exchange without real-time access to public-key authority.

Public Key Infrastructure

- A system to securely distribute & manage public keys.
- Important for wide-area trust management (e.g., for e-commerce)
- Ideally consists of
  - a certification authority
  - certificate repositories
  - a certificate revocation mechanism (CRLs, etc.)
- Many models possible:
  - monopoly
  - delegated
  - oligarchy
  - anarchy

Monopoly Model

- Single organization is the certificate authority (CA) for everyone
- Shortcomings:
  - no such universally-trusted organization
  - requires everyone to authenticate physically with the same CA
  - compromise recovery is difficult (due to single embedded public key)
  - once established, CA can abuse its position (excessive pricing, etc.)
  - requires perfect security at CA
- CA may trust registration authorities (RAs) to check identities in order to do the initial authentication
  - Solves the problem of physically meeting the CA.

Delegated CAs

- Root CA certifies lower-level CAs to certify others
- All verifiers trust the root CA & verify certificate chains beginning at the root (i.e., the root CA is the trust anchor of all verifiers)
- Example: A national PKI, where a root CA certifies institutions, ISPs, universities who in turn certify their members
- Limitations are similar to monopoly with RAs

Oligarchy

- Many root CAs exists trusted by verifiers
- The model of web security
- Solves the problems of single authority (e.g., excessive pricing)
- Disadvantages:
  - n security-sensitive sites instead of one. Compromise of any one compromises the whole system
  - users can easily be tricked into trusting fake CAs. (depending on implementation)

Anarchy

- Each user decides whom to trust & how to authenticate their public keys
- Certificates issued by arbitrary parties can be stored in public databases, which can be searched to find a path of trust to a desired party
- Works well for informal, non-sensitive applications
  - For example, in PGP, each person creates its public key certificate and distributes it to his/her friends

Revocation

- Mechanisms to cancel certificates compromised before expiration
- Certificate Revocation List (CRL): list of revoked certificates, published periodically (mostly daily) by the CA
- Delta CRLs: Only the changes since the last issue are published
- Online Revocation Servers: No CRL is published. Verifier queries a central server to check if a certificate has been revoked.

X.509 Authentication Service

- Part of X.500 directory service standards.
  - Started 1988
- Defines framework for authentication services:
  - Defines that public keys stored as certificates in a public directory.
  - Certificates are issued and signed by certification authority.
- Used by numerous applications and protocols: SSL, IPSec.

Contents of X.509 Certificates

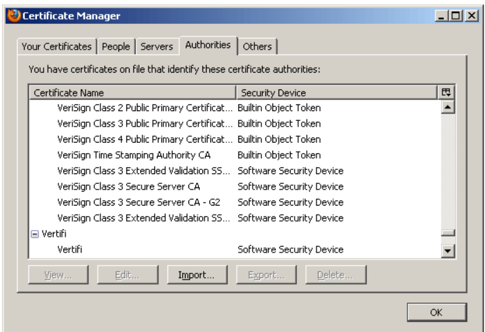
- version (1, 2, or 3)
- serial number (unique within CA) identifying certificate
- signature algorithm identifier
- issuer X.500 name (CA)
- period of validity (from - to dates)
- subject X.500 name (name of owner)
- subject public-key info (algorithm, parameters, key)
- issuer unique identifier (v2+)
- subject unique identifier (v2+)
- extension fields (v3)
- signature (of hash of all fields in certificate)

How to Obtain a Certificate?

- For a particular application, you can define your own CA (libraries like OpenSSL provide the necessary tools)
  - Many companies define their own CA.
- Trusted CAs provide certificates for other companies and persons. Some examples for CAs
  - Verisign, Thawte, COMODO

Default Certificates in Browser

- You can see certificates accepted by your browser.
  - Example: In Firefox: Preferences/Advanced/Certificates

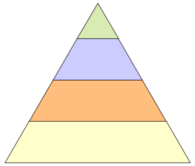


Validity of Certificates

- Certificates are valid if:
  - Signature of CA verifies
  - Dates of the certificate are valid
  - Certificate was not revoked
- Certificates can be revoked before expiration if
  - user's private key is compromised
  - user is no longer certified by this CA
  - CA's certificate is compromised
- CA maintains a list of revoked certificates, Certificate Revocation List (CRL)
- Users should check certificates with CA's CRL

CA Hierarchy

- X509 entities have different CAs; in this case CAs how is a certificate verified?
  - Start with the subject
  - CAs must form a hierarchy
  - Certificate's linking members of hierarchy are used to validate other CAs
  - Each CA has certificates for clients (forward) and parent (backward)
  - Each client trusts parent's certificates



Problems with X509

- Management of certificates
- Assumptions about validity of certificates:
  - detection of secret key disclosure
    - Time between disclosure and detection may be in hours or days, time needed for abuse may be counted in milliseconds
    - Owner is responsible for private key usage until requesting CA to revoke appropriate certificate
  - time delay for certificate revocation
  - time delay for distribution of revoked certificates
  - amount of data distributed periodically by CA

Problems with X509 – 2

- CRL problems
  - Protocols must check CRLs to make sure that the certificate is still valid
  - In practice protocols do not really check CRLs, delay between revocation and detection of revocation
  - CRL is not suitable for time-critical applications
  - Time-validity of CRL is typically 24 hours
    - Validity of certificates is usually years