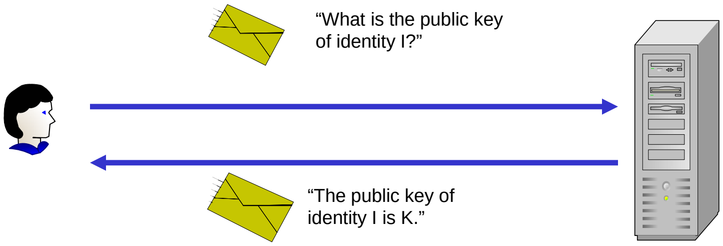
Authentication

- Digital signature validation proves:
  - message was not altered in transmission
  - came from owner of the private key
- How does a “relying party” know to whom the private key belongs?
  - Key Servers
  - Certificates

Key Server

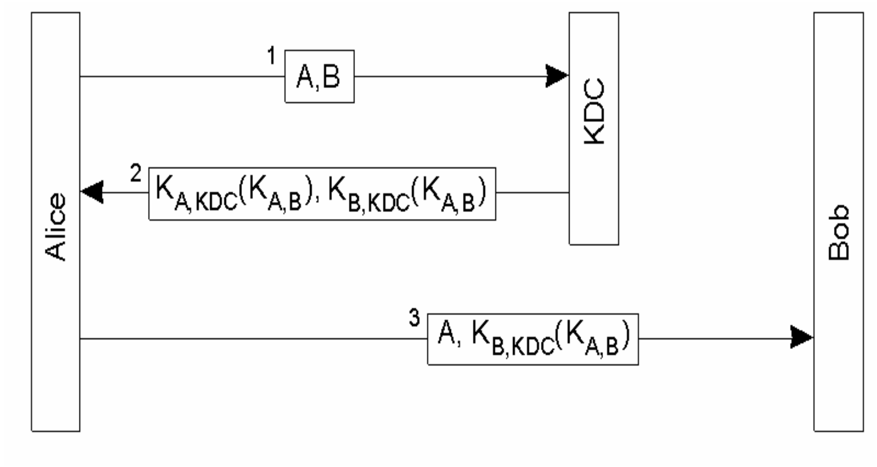


“What is the public key of identity I?”

“The public key of identity I is K.”

- The key server stores [identity, public key] pairs
- The key request can be in plaintext
- The key server reply is encrypted using the private key of the key server
- The public key of key server is known to the relying party
- The key server can be a point of attack or performance bottleneck
- The key server must be trustworthy
- Observations:
  - the relying party only cares about the reply
  - the reply can be precomputed and distributed

Authentication using a Key Server



Alice

KDC

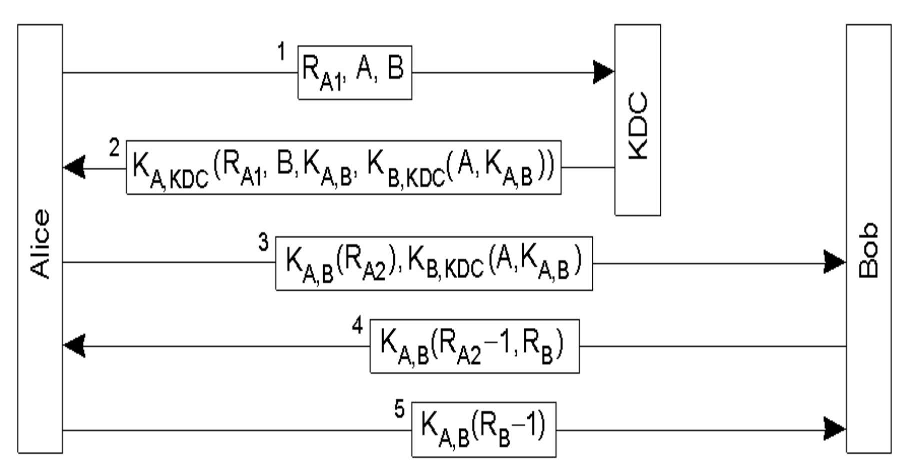
Bob

1 A,B

2 $K_{A,KDC}(K_{A,B}), K_{B,KDC}(K_{A,B})$

3 $A, K_{B,KDC}(K_{A,B})$

Needham-Schroeder Protocol



Alice

KDC

Bob

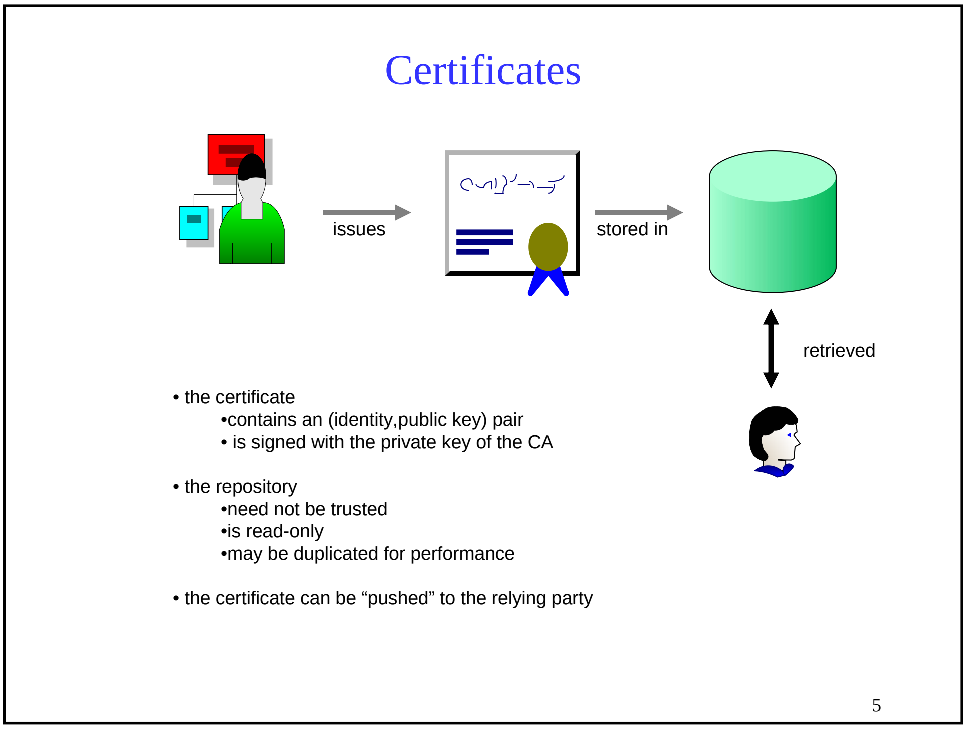
1 R_{A1}, A, B

2 $K_{A,KDC}(R_{A1}, B, K_{A,B}, K_{B,KDC}(A, K_{A,B}))$

3 $K_{A,B}(R_{A2}), K_{B,KDC}(A, K_{A,B})$

4 $K_{A,B}(R_{A2}-1, R_B)$

5 $K_{A,B}(R_B-1)$



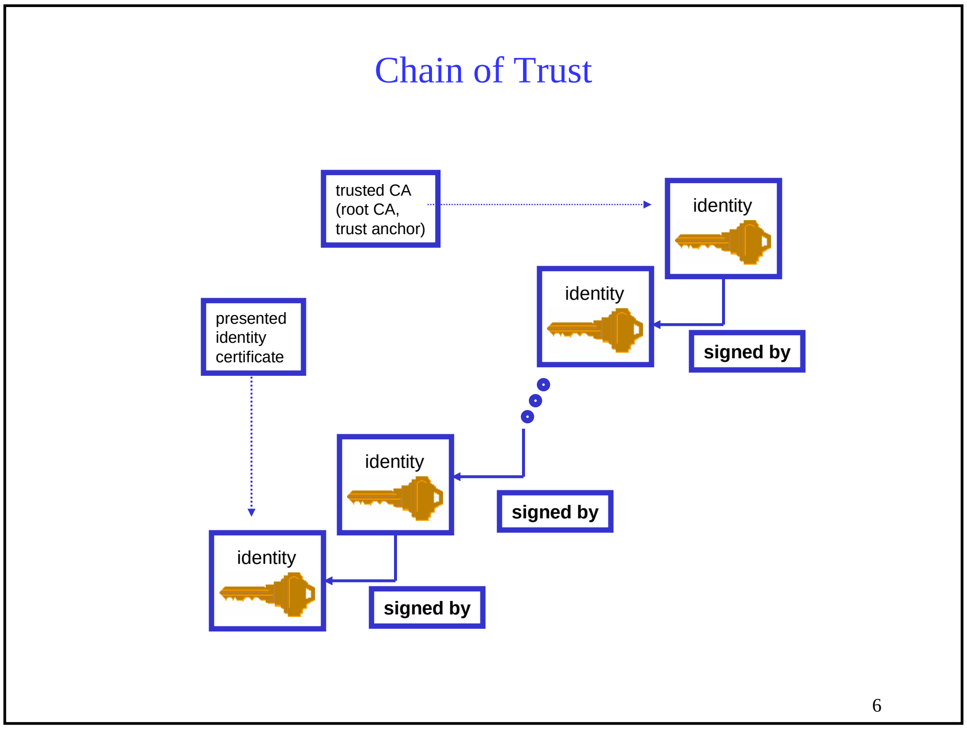
Certificates

issues

stored in

retrieved

- the certificate
  - contains an (identity,public key) pair
  - is signed with the private key of the CA
- the repository
  - need not be trusted
  - is read-only
  - may be duplicated for performance
- the certificate can be “pushed” to the relying party



Chain of Trust

trusted CA
(root CA,
trust anchor)

identity

identity

signed by

presented
identity
certificate

identity

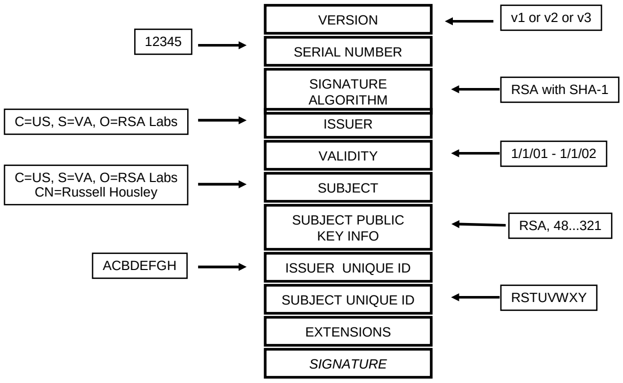
signed by

identity

signed by

Certifica

X.509 Certificate Format



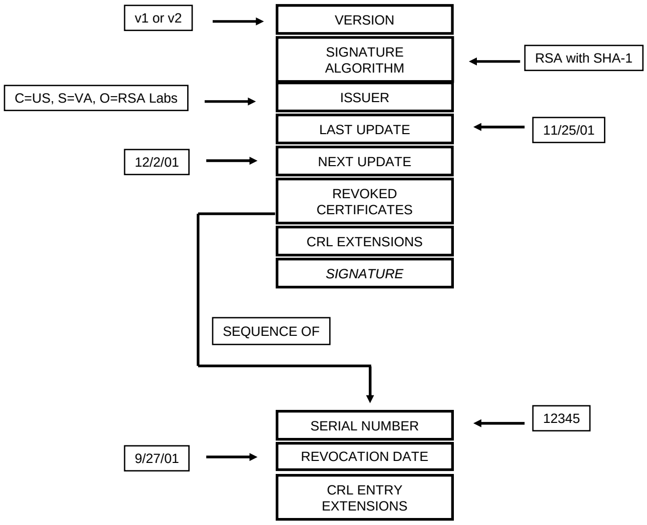
Example Certificate

```
Certificate:
    Data:
       Version: 3 (0x2)
       Serial Number: 1097588 (0x10bf74)
       Signature Algorithm: md5WithRSAEncryption
       Issuer: C=US, ST=Massachusetts, O=Massachusetts Institute of Technology, OU=Client CA v1
       Validity
          Not Before: Jul 31 14:07:49 2000 GMT
          Not After : Jul 31 14:07:49 2001 GMT
       Subject: C=US, ST=Massachusetts, O=Massachusetts Institute of Technology, OU=Client CA v1, CN=Jeffrey I Schiller/Email=jis@MIT.EDU
       Subject Public Key Info:
          Public Key Algorithm: rsaEncryption
          RSA Public Key: (1024 bit)
             Modulus (1024 bit):
                00:cf:01:0a:e5:f1:3c:60:c1:f2:c1:ca:99:96:1d:
                7d:39:97:8c:72:cf:e8:7c:51:a1:84:a4:5b:b8:b3:
                3a:dc:dd:c5:99:76:cb:5d:b1:24:86:67:46:52:45:
                69:09:fb:01:b0:dd:41:02:de:27:c2:b7:cd:b1:cd:
                47:9a:ae:55:bb:83:cd:bd:c1:aa:2b:23:3d:85:06:
                e0:4a:6c:a8:af:b4:cb:64:ea:c9:33:f7:ef:a9:8f:
                d9:7a:20:68:a1:09:c4:4e:62:20:00:d1:fd:a5:7c:
                14:90:48:79:a9:7d:ef:f5:46:b6:fb:4e:c5:fc:94:
                8f:11:bf:1a:ef:7b:2d:06:ef
             Exponent: 65537 (0x10001)
       X509v3 extensions:
          X509v3 Key Usage:
             ....
          1.2.840.113554.1.3.1:
             0....]/e.ii;....m......j....Nr....$wF..t...QZ...
    Signature Algorithm: md5WithRSAEncryption
       30:4c:3b:a5:d8:11:e1:04:61:d2:39:ff:e1:74:c3:06:2f:3b:
       52:59:9c:75:05:2e:31:cc:c3:99:5c:02:e5:67:bf:06:99:7f:
       c8:2a:5b:dd:bd:67:a5:a7:98:74:14:44:a7:db:76:19:9c:80:
       0a:58:1d:53:35:d0:75:82:9d:2a:e7:12:53:3f:8b:60:cc:a3:
       c9:5b:dd:34:b6:a4:33:a9:a5:93:64:3e:50:0d:e4:ae:a8:5d:
       c9:8d:f9:96:68:22:cd:66:3d:eb:66:11:68:04:f6:3d:64:05:
       62:64:01:41:af:23:f9:d2:a3:5b:be:e3:33:45:71:08:05:e2:
       2a:6e
```

Revocation

- Is a certificate still valid?
  - Private key compromise
  - CA compromise
  - Affiliation changed
  - Superseded
  - CA ceased operation
  - …
- Certificate Revocation List (CRL) provides a list of the unexpired certificates that should no longer be used

CRL Format



v1 or v2 → VERSION

SIGNATURE ALGORITHM ← RSA with SHA-1

C=US, S=VA, O=RSA Labs → ISSUER

LAST UPDATE ← 11/25/01

12/2/01 → NEXT UPDATE

REVOKED CERTIFICATES

CRL EXTENSIONS

SIGNATURE

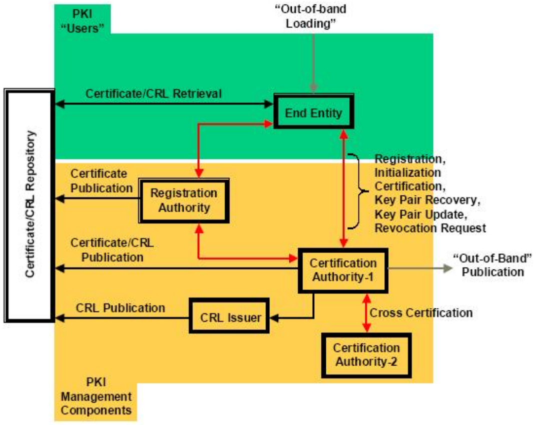
SEQUENCE OF

SERIAL NUMBER ← 12345

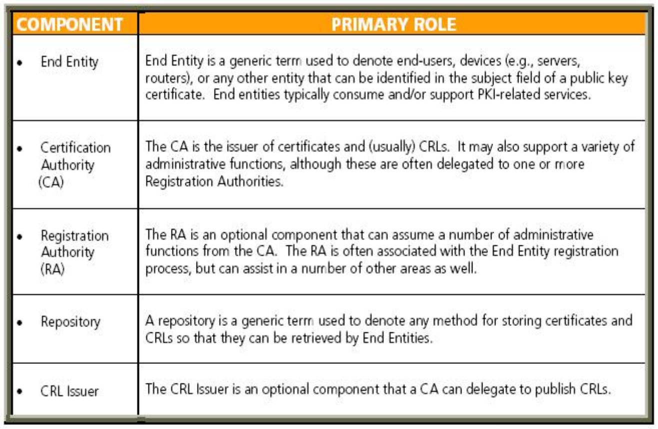
9/27/01 → REVOCATION DATE

CRL ENTRY EXTENSIONS

PKIX Architecture


PKI "Users"
"Out-of-band Loading"
Certificate/CRL Retrieval
End Entity
Certificate/CRL Repository
Registration, Initialization Certification, Key Pair Recovery, Key Pair Update, Revocation Request
Certificate Publication
Registration Authority
Certificate/CRL Publication
Certification Authority-1
"Out-of-Band" Publication
CRL Publication
CRL Issuer
Cross Certification
Certification Authority-2
PKI Management Components

PKIX Elements

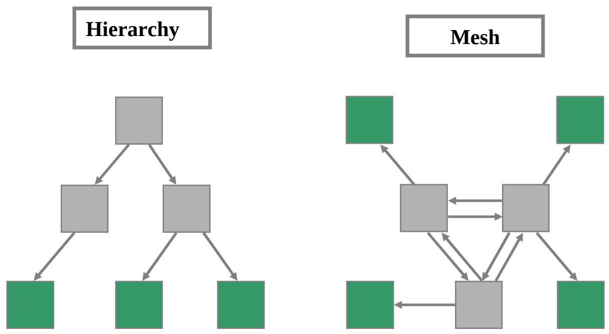


COMPONENT	PRIMARY ROLE
• End Entity	End Entity is a generic term used to denote end-users, devices (e.g., servers, routers), or any other entity that can be identified in the subject field of a public key certificate. End entities typically consume and/or support PKI-related services.
• Certification Authority (CA)	The CA is the issuer of certificates and (usually) CRLs. It may also support a variety of administrative functions, although these are often delegated to one or more Registration Authorities.
• Registration Authority (RA)	The RA is an optional component that can assume a number of administrative functions from the CA. The RA is often associated with the End Entity registration process, but can assist in a number of other areas as well.
• Repository	A repository is a generic term used to denote any method for storing certificates and CRLs so that they can be retrieved by End Entities.
• CRL Issuer	The CRL Issuer is an optional component that a CA can delegate to publish CRLs.

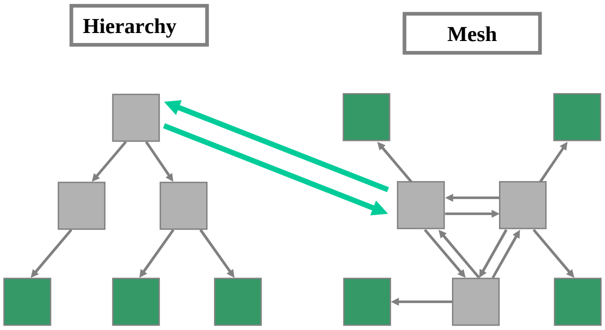
Role of the CA

- Verifies certificate request information
- Generates and digitally signs the certificate
- Revokes certificate if information changes
- Revokes certificate if private key is disclosed
- Support certificate hierarchies
- Optional services
  - Key generation
  - Issue hardware token

CA Topologies



Cross Certification


Hierarchy
Mesh