CS 578 – Cryptography

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Certificates and Authentication Methods

June 23, 2006

Administrative Announcements

- Handouts:
  - New lecture notes

Recall: Signature Schemes

- Setup: Generates secret key sk, public (verification) key pk
- Sign(sk,m) outputs sig
- Verify(pk,m,sig): outputs “yes” or “no
- Security: Existential unforgeability under chosen-message attack (CMA)

Recall: Signature Schemes

- Built signature scheme from one-way functions
- From generic one-way functions
  - One-time signatures, can be extended
  - Fast, but signatures are long
- $F^{DLog}(x) = g^x \bmod p$
  - Can built signatures out of this
  - ElGamal signatures, Schnorr signatures, DSA

Recall: Full-Domain Hash

- Works for every trapdoor permutation. S(sk,m):
  - D := Hash(m) for Hash: {0,1}* → M_{pk}
  - sig := F^{-1}(sk,D)

  (Hash: collision-resistance + maps into the full set M_{pk} (thus the name "full domain"))
- V(pk,m,sig):
  - Test if F(pk,sig) = Hash(m)

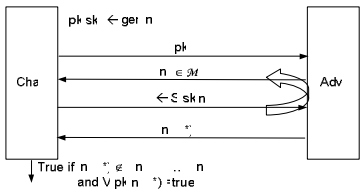
Full-Domain Hash

- Theorem (Bellare, Rogaway'94): If hash is a "random oracle" then FDH is existentially unforgeably under chosen-message attack assuming that F is one-way.

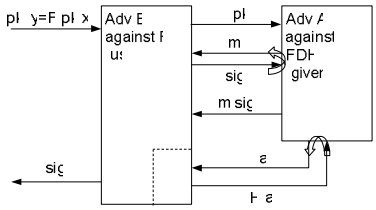
  [proof on the board]

Recall: CMA-Security of Signatures

- For a signature scheme Sig = (Gen,S,V), define the following CMA game:



Full-Domain Hash – Proof Sketch



Summary of Digital Signatures

- CMA-secure signature schemes exist if OWF exist
- First one-time signatures: Lamport, Merkle, etc.
- ElGamal signatures: Security based on hardness of discrete logarithms, security not proven, relies on ability to solve equations in the exponents, common variants: Schnorr, DSA
- RSA-based signatures: Naïve use insecure, Full-domain Hash (FDH) based on any trapdoor permutation. CMA-secure in the random oracle model
- Hash-then-Sign: Often used in practice, however not mandatory (!), lots of books do as if this had to be done
- Today: Key management, certificates, trust

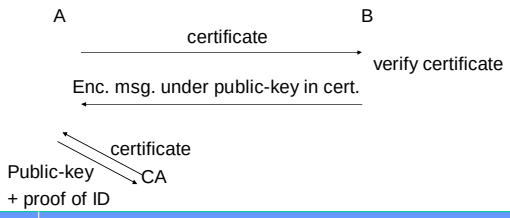
Public-key Management

- How does Alice authentically obtain Bob's public key?
- Main classes of possibilities:
  - Personally on disk
  - From public pk-dictionaries
  - Over the web with a certificate of a certification authority (CA)
  - Over a chain of people she knows

Public-key Management

- How does Alice obtain Bob's public key?

1. Single Domain Certification Authority (CA)



Public-key Certification

- Public-key certification by X509.V3
- Cert = ([X500 Subject ID (home,org.,address)
  X500 Signer ID/issuer,
  the public key pk that is signed,
  validity dates,
  serial number,
  other extensions, …]
  || Sign(sk_{CA}, […])

Public-key Certification

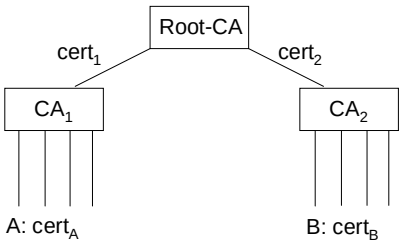
- [Certificates in Browser]

Public-key Certification

- Remarks:
- Alice obtains certificates offline, and CA is an offline entity
- Verify Alice's certificates requires Bob to have the CA's public-key
- CA is a trusted party
- CA's signing key has to be highly guarded

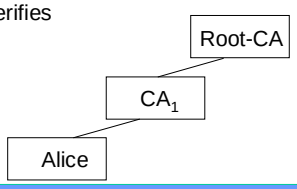
Cross-domain Certification

2. Cross Domain Certification

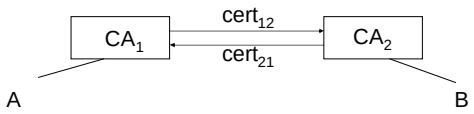


Cross-domain Certification (cont'd)

- Everyone has to have the root-CA public-key
- Alice's certificate: [Alice's info, CA_1's sig] || [CA_1's info,root-CA's sig]
- Bob verifies

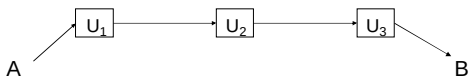


Cross-domain Certification (cont'd)



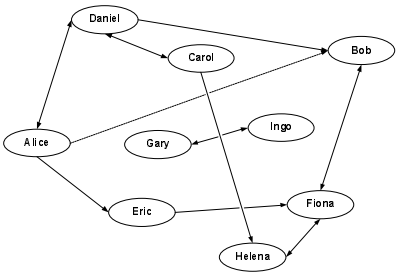
- A → B: $cert_{12}$ || $cert_{21}$ + signed/encrypted message

Web of Trust (PGP)

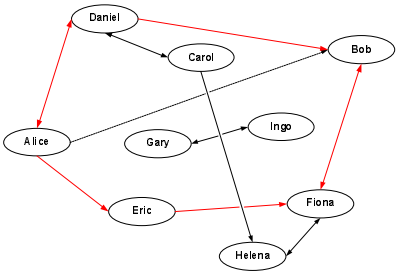


- $Cert_A$ = [cert(U_1 → A), cert(U_2 → U_1), cert (U_3 → U_2)]

Web of Trust Graph



Web of Trust Graph



Trust Evaluation due to Maurer

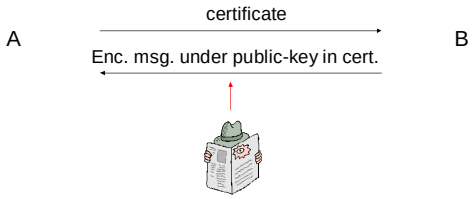
- Every user B maintains predicates:
  - Aut(X): B considers public key of X authentic
  - Cert(X,Y): B maintains certificate issued by X on pk of Y
  - Trust(X,1): B trusts X that X correctly checks identities before issuing a certificate
  - Rec(X,Y,1) “recommendation of depth 1”: B has (attribute) certificate of X, stating that X trusts Y to correctly issue certificates.
- Inductive extension:
  - Trust(X,i): B trusts X that X correctly issues recommendations of order i-1
  - Rec(X,Y,i): corresponding certificate

Trust Evaluation due to Maurer

- Evaluation rules: Meaning for Cert:
  $Aut(X) \wedge Trust(X,1) \wedge Cert(X,Y) \rightarrow Aut(Y)$
- Evaluation rules: Meaning for Rec:
  $Aut(X) \wedge Trust(X,i+1) \wedge Rec(X,Y,i) \rightarrow Trust(Y,i)$
- Allows for deducing trust. Starting point:
  - All Aut(P) for which B has identified person P himself
  - All Trust(P,i) that B considers true himself
  - All certificates B possesses, encoded as cert or rec
- Remark:
  - Trust(X,1), Rec(X,Y,1): Trust in humans to carefully certify
  - Trust(X,2), Rec(X,Y,2): Trust in knowledge of human nature
  - Trust(X,≥3), Rec(X,Y,≥3): Hard to understand

Active Attacks against Certification Sending

- Active attacks against sending of certificates?



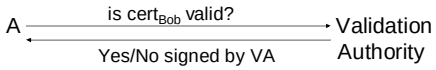
Certificate Revocation

- How to revoke A's certificate?

1. Expiration date in credential (e.g., one year)
2. CRL: Certificate Revocation List:
   Post list of revoked certificates signed by the CA
   - Problem: CRLs become long
   - Δ-CRL: signed incrementally to CRL.

Certificate Revocation

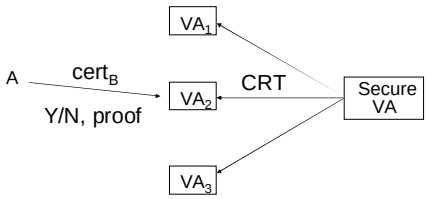
3. OCSP: Online Certificate Status Protocol



- Problems:
  - High load on VA → Replicate VA's key all over the world (but then key at risk)

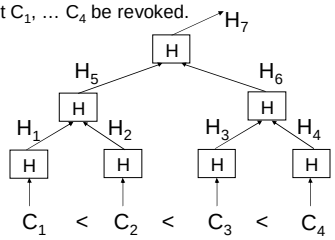
Certificate Revocation

4. Certificate Revocation Tree (CRT)



Certificate Revocation (cont'd)

- Let C_1, … C_4 be revoked.



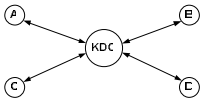
- CRT = [C_1,C_2 ,C_3,C_4 + sign($sk_{root\text{-}VA}$, (tree-depth, H_7))

Certificate Revocation (cont'd)

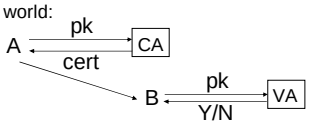
- Proof that, e.g., C_2 was revoked.
  - VA sends [sign($sk_{root-VA}$, (tree-depth, H_7)), H_1, H_6]
  - Alice hashes C_2 , then compute tree and check depths and if root is H_7
  - For n revoked certificates, proof size is O(log n)
- Proof that C was not revoked, i.e., $C \notin CRT$
  - Say $C_1 < C < C_2$
  - VA sends [sign($sk_{root-VA}$, (tree-depth, H_7)), H_1, H_2, H_6, C_1, C_2]
- Answering a request incorrectly requires breaking the hash function (strictly: breaking 2nd pre-image collision-resistance of H)

Distribution of Sym. and Pub. Keys

- Comparison: distribution of symmetric / public keys.
- Recall symmetric case: Key Distribution Center (KDC)



- Public-key world:



Distribution of Sym. and Pub. Keys

- KDC
  - is online: needed for every new session
  - is compromised → all past and future sessions are exposed
  - fast
- CA
  - is offline, but VA is online
  - is compromised → then future sessions exposed (forward secrecy)
  - slow