PKI - Public Key Infrastructure

Identification and Public Key

- Every node has an ID
- Every node has a public key
- The association between the ID and the key is critical

- A central question: is this the public key for node X?
  - X is the ID

PKI

- PKI consists of those components that are used to securely distribute public keys
  - Certificates
  - A repository for retrieving certificates
  - A method for revoking certificates
  - A method for evaluating certificates

A Preliminary Solution

- A node encrypts (signs) its public key with its private key

  {*e*} *d* □ recipient
- The recipient can only decrypt using the public key in question
  - Thus confirm that ***e*** is the public key of the signing guy
- But who is the signing guy?
- It won't help by adding the ID, either

  {*e*, Alice} *d* □ recipient

  since the ***e*** and ***d*** here can actually belong to Eve!

Certificate-Based Solution

- A **certificate** is a token that binds an identity to a cryptographic key
- A **certificate authority** (CA) issues certificates

Two Types of Certificates

- Signature-less certificate
  - Merkle's Tree Authentication Scheme
  - Such a certificate contains an *authentication path*
- Signed certificate

$$C_{Alice} = \{e_{Alice} \,||\, Alice \,||\, T\}\, d_{Cathy}$$

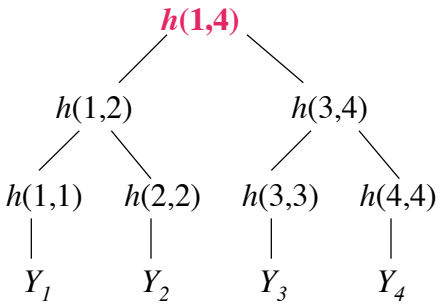
Merkle's Tree Authentication Scheme

- All <id, public key> pairs are stored in a file
- A cryptographic hash function creates a digest of the file
  - The digest is known to the public
- If any pair is changed, it will be detected
  - Since the digest will be different

Digest Algorithm

- A tree-based algorithm

Y_1	Cathy	01389234789357
Y_2	Bob	89230378597823
Y_3	Alice	72384927894027
Y_4	David	32748902378240



Signature-Less Certificate Verification

- How can Bob verify whether or not Alice's public key is 72384927894027.
- Bob will re-compute the digest, and compare that with the publicly known value of the digest
  - If Alice's public key is not 72384927894027, a discrepancy will be detected

Y_1	Cathy	01389234789357
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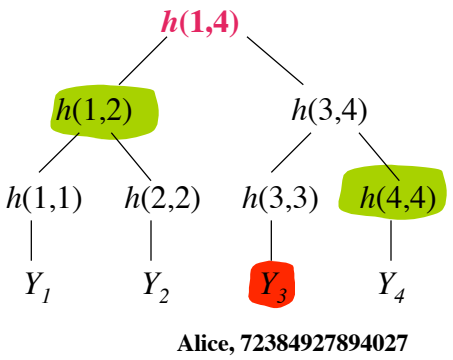

Alice, 72384927894027

Authentication Path

- Bob knows Y_3
- Bob needs to know $h(4,4)$ and $h(1,2)$
- Y_3, $h(4,4)$ and $h(1,2)$ is the **authentication path** for Alice's public key
  - They can put together and used for certifying Alice's public key

Verifying A Signed Certificate

- Suppose Bob knows Cathy's public key e_{Cathy}
- When Bob obtains C_{Alice},
  - Deciphers C_{Alice} using e_{Cathy}
  - Then knows that Cathy is vouching that e_{Alice} is Alice's public key, issued at time T
  - If Bob trusts what Cathy believes
  - Then Bob knows e_{Alice} is Alice's public key
- But, Bob Has to Know e_{Cathy}!

- We focus on the signed certificate below

PKI Trust Models

- Monopoly Model
- Monopoly + Registration Authorities (RA)
- Delegated CAs
- Oligarchy
- Anarchy

Monopoly Model

- One single CA for everybody
- There is no one universally trusted organization
- Hard to reconfigure once everybody uses a single CA
- Can be remote from many principals
- Entire world relies on a single entity!

Monopoly + RAs

- Well, one can contact a local RA for a certificate
- The local RA will verify identity, securely communicates with the CA, and then the CA issues a certificate
- CA actually just rubber-stamps

Delegated CAs

- A trusted CA can issue certificates to other CAs
  - Users can then obtain certificates from one of the delegated CAs, instead of just a single trusted CA

Oligarchy

- A product comes with MULTIPLE trusted CAs
- Often used in browsers
- If one is broken, security is broken

Anarchy Model

- Everyone has its own trusted CAs
  - Probably everyone has different ones

Certificate Signature Chains

- *X.509*
- *PGP*

- Tree-like CA hierarchy employed
  - Every node has a local CA
  - A local CA has its CA, the parent
  - The parent CA has its parent
  - And there is a root CA
  - Together, a tree of CAs!

X.509

- X.509 defines certificate formats and validation in generic context
  - X.509v3 is the current version
- Format:
  - Version, serial number
  - issuer's name, id, signature algorithm id
  - subject's name, id, public key, validity interval
  - extensions
  - Signature

Certificate Chains

- Cathy certifies Dan's public key
  - Cathy <<Dan>>
- If Dan <<Bob>>, Bob<<David>>, and Alice knows Cathy's public key,
  - then a certificate chain is formed
  - Alice can validate Bob's public key by going through the chain

PGP Certificate Chains

- PGP (Pretty Good Privacy) provides privacy for email
  - Can also be used to sign files
  - We look at OpenPGP below
- An OpenPGP certificate is a sequence of packets
  - A public key packet followed by 0+ signature packets
  - Each packet is a record with a tag describing its purpose

Public Key Packet

- Version
- Creation time
- Validity period
- Public key algorithms (and parameters)
- Public key (of course)

Signature Packet

- Version
- Signature type
  - Also encodes a level of trust
- Creation time
- Key identifier of the signer
- Public key algorithm
- Hash algorithm
- Part of signed hash value
- Signature (of course!)

PGP Certificate Features

- PGP certificate allows multiple signatures
- Each signature has a different level of "trust"

- Different from X.509

PGP Certificate Chain Example

Alice is verifying Bob's public key

- Ellen, Fred, Giselle, Bob <<Bob>>
- Henry, Irene, Giselle <<Giselle>>
- Ellen, Henry <<Henry>>
- Jack, Ellen <<Ellen>>

Then: Henry<<Henry>>, Henry<<Giselle>>, Giselle<<Bob>>
Jack<<Ellen>>, Ellen<<Bob>>