Principles of Network Security (cont.)

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Authentication: version 1.0

Authentication: Bob wants Alice to “prove” her identity to him.

Protocol ap1.0: Alice says "I am Alice".

“"I am Alice“”

Failure scenario??

Trudy can simply declare herself to be Alice

Authentication: version 2.0

Protocol ap2.0: Alice says “I am Alice” and sends her secret password to “prove” it.

“"I am Alice“”

Failure scenario??

playback attack: Trudy records Alice’s packet and later plays it back to Bob
**Authentication: version 3.0**

**Goal:** avoid playback attack

**Nonce:** number (R) used only once–in-a-lifetime

ap3.0: Bob sends Alice a nonce, R. Alice must return R, encrypted with shared secret key

"I am Alice"

R

\( K_{A-B}^*(R) \)

only Alice knows key to encrypt nonce, so it must be Alice!

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**Authentication: version 4.0**

ap3.0 requires shared symmetric key. Key distribution can be a problem.

ap4.0: use nonce, public key cryptography.

"I am Alice"

R

\( K_{A-B}^*(R) \)

Bob computes

\( K_{A-B}^*(K_A(R)) = R \)

and knows only Alice could have the private key, that encrypted R such that

\( K_{A-B}^*(K_A(R)) = R \)

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**Principles of Network Security**

- Confidentiality: cryptography
- Authentication
- Integrity
- Key distribution and certification

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**Integrity**

- Digital Signatures:
  - cryptographic technique to ensure document integrity.
  - analogous to hand-written signatures.
  - Sender (Bob) digitally signs document, establishing he is document owner/creator.
  - The recipient (Alice) receives the document and the digital signature.
  - The recipient can be sure that the document is
    - **verifiable:** Bob signed the document.
    - **nonforgeable:** the document hasn’t been changed since Bob signed it.
**Digital Signatures**

- Bob signs message \( m \) by encrypting with his private key, creating a digital signature \( K_B(m) \).

Bob’s message, \( m \)

- Suppose Alice receives \( m \) and its digital signature \( K_B(m) \).
- Alice applies Bob’s public key \( K_B \) to \( K_B(m) \) and checks whether \( K_B(K_B(m)) = m \).
- If so, whoever signed \( m \) must have used Bob’s private key.

**Problem:** Computationally expensive to public-key-encrypt long messages.

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**Message Digests**

- Apply a hash function \( H \) to \( m \), get a much smaller message digest \( H(m) \).
- Public-key-encrypt the message digest to generate the digital signature \( K_B(H(m)) \).

Good/bad hash functions?

- **Hint:** Given a hash function, it is possible for many messages sharing the same digest.

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**Signed Message Digest**

Bob sends digitally signed (small) message digest:

- Alice verifies signature and integrity of digitally signed message:

Alice’s public key

1. **Bob’s message, \( m \), signed (encrypted) with his private key.**

2. **Suppose Alice receives \( m \) and its digital signature \( K_B(m) \).**

3. **Alice applies Bob’s public key \( K_B \) to \( K_B(m) \) and checks whether \( K_B(K_B(m)) = m \).**

4. If so, whoever signed \( m \) must have used Bob’s private key.

**Problem:** Computationally expensive to public-key-encrypt long messages.

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**Internet Checksum: Poor Hash Function for Generating Message Digests**

Given a message and its Internet checksum, it is easy to find another message with the same checksum.

<table>
<thead>
<tr>
<th>message</th>
<th>ASCII format</th>
<th>message</th>
<th>ASCII format</th>
</tr>
</thead>
<tbody>
<tr>
<td>I O U 1</td>
<td>49 4F 55 31</td>
<td>I O U 2</td>
<td>49 4F 55 39</td>
</tr>
<tr>
<td>0 0 . 9</td>
<td>30 30 2E 39</td>
<td>0 0 . 1</td>
<td>30 30 2E 31</td>
</tr>
<tr>
<td>9 B O B</td>
<td>39 42 D2 42</td>
<td>9 B O B</td>
<td>39 42 D2 42</td>
</tr>
</tbody>
</table>

| B2 C1 D2 AC | | B2 C1 D2 AC |

Different messages but identical checksums!

**Hash function property:** Given digest \( x \) for message \( m \), computationally infeasible to find another message \( m' \) that shares the same digest. Pre-image resistance. Collision resistance.
Good Hash Functions for Generating Message Digests

- **MD5**
  - Computes 128-bit message digest in 4-step process.
  - Appears difficult to construct message \( m \) whose MD5 hash is equal to \( x \).
- **SHA-1**
  - [NIST, FIPS PUB 180-1]
  - 160-bit message digest
- **SHA-2**
  - More bits: SHA256, SHA512

Principles of Network Security

- Confidentiality: cryptography
- Authentication
- Integrity
- **Key distribution and certification**

Secret Key Distribution: Key Distribution Center (KDC)

- KDC: server shares different secret key with each registered user (many users).
- Alice, Bob know own symmetric keys, \( K_{A,KDC}, K_{B,KDC} \) for communicating with KDC.

Key Distribution and Certification

**Symmetric key distribution problem:**
- How do Alice and Bob establish shared secret key over network without Trudy’s knowledge?

**Public key distribution problem:**
- When Alice obtains Bob’s public key (from web site, e-mail, diskette), how does she know it is Bob’s public key, not Trudy’s?
**Key Distribution using KDC**

- Alice knows R1
- Bob knows to use R1 to communicate with Alice

Alice and Bob communicate: using R1 as session key for shared symmetric encryption

Q: How does KDC allow Bob, Alice to determine shared symmetric secret key to communicate with each other?

- $K_{A,KDC}(A,B)$
- $K_{B,KDC}(A,R_1)$

Bob computes $K_A^*(K_A(R)) = R$ and knows only Alice could have the private key, that encrypted R such that $K_A^*(K_A(R)) = R$

**Security Vulnerability with Public Key Distribution**

A case example for public key-based authentication.

**Security vulnerability when public keys are not well known**

- Man (woman) in the middle attack: Trudy poses as Alice (to Bob) and as Bob (to Alice)

$K_A^*(K_A(R)) = R$

Bob computes $K_A^*(K_A(R)) = R$ and knows only Alice could have the private key, that encrypted R such that $K_A^*(K_A(R)) = R$

**Public Key Distribution: Certification Authorities**

- Certification authority (CA): trustable by everyone; everyone knows its public key.
- E (person, router) registers its public key with CA.
  - E provides "proof of identity" to CA.
  - CA creates certificate binding E to its public key.
  - Certificate is CA-signed document saying "E's public key is ..."
Certification Authorities (cont.)

When Alice wants to verify Bob’s public key:
- gets Bob’s certificate (Bob or elsewhere).
- apply CA’s public key to Bob’s certificate, verify Bob’s public key.

Key Certification Methods

- Public key certificate signed by a certification authority
- Peer certification:
  - If A knows B personally, they can verify each other’s public keys using offline means and sign them;
- Certificate chain leading to a certificate authority
  - CA signs A’s public key certificate
  - A signs B’s public key certificate
  - B signs C’s public key certificate
  - If you trust all signers (CA, A, B in this case), then you can trust the certificate.

Summary: Principles of Network Security

Cryptography:
- symmetric keys: protocols? weakness?
- public keys: protocol? weakness?
Confidentiality:
- only sender, intended receiver should “understand” message contents
Authentication:
- sender, receiver want to confirm identity of each other
Message Integrity:
- sender, receiver want to ensure message not altered (in transit, or afterwards)
Key Distribution and Certification:
- problem and solution for symmetric / public keys

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