**Principles of Network Security**

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**Who might Bob and Alice be?**

- Web browser/server for electronic transactions (e.g., on-line purchases/banking)
- DNS servers
- Routers exchanging routing table updates
- ... well, real-life Bobs and Alices!

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**The Network Security Model**

- Bob and Alice want to communicate “securely”.
- Trudy (the adversary) has access to the channel.

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**What can an adversary do?**

- **Eavesdrop:** understand the content of messages
- **Actively changing** messages
- **Impersonation:** fake (spoof) identity
- **Denial of service:** prevent service from being used by others (e.g., by overloading resources)
What is Network Security?

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).

Access and Availability: services must be accessible and available to (and only to) legitimate users.

Principles of Network Security

- Confidentiality: cryptography
- Authentication
- Integrity

The Language of Cryptography

First goal of cryptography: confidentiality.

- Symmetric key crypto: encryption and decryption keys are identical. (both are secret)
- Public key crypto: encryption key is public, decryption key is secret.

Symmetric Key Cryptography: Monoalphabetic Cipher

Monoalphabetic cipher: substitute one letter for another.

plaintext: abcdefghijklmnopqrstuvwxyz

ciphertext: mnbvcxzasdfghjklpoiuytrewq

Example: Plaintext: bob. i love you. alice
ciphertext: nkn. s gktc wky. mgsbc

Q1: How hard to break this simple cipher?
- brute force?
- other?

Q2: How to make it more difficult to break?
Symmetric Key Cryptography: DES

**DES: Data Encryption Standard**
- US encryption standard [NIST 1993]
- 56-bit symmetric key, 64-bit plaintext input
- encryption: initial permutation $\Rightarrow$ 16 "rounds", each using different 48 bits of key $\Rightarrow$ final permutation
- decryption: reverse operation using the same key

- How secure is DES?
  - DES Challenge (1999): 56-bit key-encrypted phrase decrypted (brute force) in 22 hours 15 minutes

- Making DES more secure:
  - use three keys sequentially (3-DES)
  - use more bits

**Stream Cipher**

- Fixed-size key K expanded to an infinite random stream C(K)
- For data X, it uses an portion of the key stream (equal length to data X), then xor the data to produce encrypted data
- Same key cannot be used twice, otherwise
  - Encrypted(X) = X xor C(K)
  - Encrypted(Y) = Y xor C(K)
  - Encrypted(X) xor Encrypted(Y) = X xor Y
  - If you know X (or Y), then you know the other
  - Even if you know neither, you can guess X and Y quite well from X xor Y if X and Y are in a natural language

- Used in the WEP wireless encryption
  - Employ an initialization vector of 24-bit, but insufficient

AES: Advanced Encryption Standard

- Newer (Nov. 2001) symmetric-key NIST standard, replacing DES
- Processes data in 128 bit blocks
- 128, 192, or 256 bit keys
- Brute force decryption (try each key) taking 1 sec on DES, takes 149 trillion years for 128-bit AES

Public Key Cryptography

- Symmetric key cryptography
  - requires sender, receiver know shared secret key
  - Q: how to agree on key in the first place? (particularly difficult if Trudy is eavesdropping on all communication)

- Public key cryptography
  - encryption key is different from decryption key
  - encryption key is public, known to everyone, also called public key
  - decryption key is secret, known only to receiver, also called private key
Public Key Cryptography

**Bob’s public key**

plaintext message, m

**K_B**

encryption algorithm

**K_B(m)**

ciphertext

decryption algorithm

**m = K_B(K_B(m))**

plaintext message

**Bob’s private key**

*Principle for choosing the public/private key pair:*

One should not be able to derive the private key from the public key.

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Public Key Cryptography: RSA

(Ron Rivest, Adi Shamir and Len Adleman)

- Choosing keys:
  - Choose two large prime numbers p, q. (e.g., 1024 bits each)
  - Compute n = pq, z = (p-1)(q-1)
  - Choose e (with e<n) that has no common factors with z
  - Choose d such that ed-1 is exactly divisible by z
  - Public key is (n,e). Private key is (n,d)
- To encrypt a message, m (<n): do c = m^e mod n
- To decrypt a received ciphertext, c: do m = c^d mod n
- Reason: for any m (relatively prime with n)
  - m^e mod n = 1; therefore m^ed mod n = 1
- Another property: (m^e mod n)^d mod n = m
- RSA is much slower than the symmetric key cryptos

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Principles of Network Security

- Confidentiality: cryptography
- Authentication
- Integrity

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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

“I am Alice”
### Authentication: version 2.0

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

**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.

### Authentication: version 4.0

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

**ap4.0:** use nonce, public key cryptography.

### Principles of Network Security

- **Confidentiality:** cryptography
- **Authentication**
- **Integrity**
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 m by encrypting with his private key, creating a digital signature $K_B(m)$

```
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```
Dear Alice
Oh, how I have missed you. I think of you all the time! ...(blah blah blah)
```

Bob

- 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.

Signed Message Digest

- Bob sends digitally signed (small) message digest:
  - $H(m)$
  - Bob’s private key $K_B$

```
Bob sends digitally signed (small) message digest:
```

```
large message m
```

```
H: Hash function
```

```
H(m)
```

```
digital signature (encrypt)
```

```
K_B(H(m))
```

Alice verifies signature and integrity of digitally signed message:

```
Bob’s public key $K_B$
```

```
Bob’s message, m, signed (encrypted) with his private key
```

```
Public key encryption algorithm
```

```
Bob’s private key
```

```
Bob’s message, m
```

```
Dear Alice
```

```
Oh, how I have missed you. I think of you all the time! ...(blah blah blah)
```

```
```

Problem: computationally expensive to public-key-encrypt long messages.

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.
Internet Checksum: Poor Hash Function for Generating Message Digests

Given a message and its Internet checksum, it is easy to find another message with 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 9</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  different messages  B2 C1 D2 AC  but identical checksums!

Hash function property: given digest x for message m, computationally infeasible to find another message m' that shares the same digest.

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

http://en.wikipedia.org/wiki/Cryptographic_hash_function

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)

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