15-410

"...What about gummy bears?..."

Security Applications
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PGP diagram shamelessly stolen from 15-441

Synchronization

P3extra and P4 hand-in directories have been created

- Please check ***IMMEDIATELY*** to make sure yours is there
- Please make sure you can store files there
- Check disk space

Outline

Today

- Warm-up: Password file
- One-time passwords
- Review: private-key, public-key crypto
- Kerberos
- SSL
- PGP
- Biometrics

Disclaimer

- Presentations will be key ideas, not exact protocols

Password File

Goal

- User memorizes a small key
- User presents key, machine verifies it

Wrong approach

- Store keys (passwords) in file
- Why is this bad? What is at risk?

Hashed Password File

Better

- Store hash(key)
- User presents key
- Login computes hash(key), verifies

Password file no longer must be secret

- It doesn't contain keys, only key *hashes*

Vulnerable to *dictionary* attack

- Cracker computes hash("a"), hash("b"), ...
- Once computed, hash ⇒ password list attacks *many users*

Can we make the job harder?

Salted Hashed Password File

Choose random number when user sets password

- Store #, hash(key,#)

User presents key

- Login looks up user – gets #, hash(key,#)
- Login computes hash(typed-key,#), checks

Comparison

- Zero extra work for user, trivial space & work for login
- Cracker must compute a *much larger* dictionary
  - (all “words”) X (all #'s)

Can we do better?

Shadow Salted Hashed Password File

Protect the password file after all

"Defense in depth" - Cracker must

- Either
  - Compute enormous dictionary
  - Break system security to get hashed password file
  - Scan enormous dictionary
- Or
  - Break system security to get hashed password file
  - Run dictionary attack on each user in password file

There are probably easier ways into the system

- ...such as bribing a user!

One-time passwords

What if somebody *does* eavesdrop?

- Can they undetectably impersonate you forever?

Approach

- System (and user!) store key *list*
  - User presents head of list, system verifies
  - User and system *destroy key at head of list*

Alternate approach

- Portable cryptographic clock (“SecureID”)
  - Sealed box which displays E(time, key)
  - Only box, server know key
  - User types in display value as a password

Private-Key Cryptography

Concept: *symmetric* cipher

```
cipher = E(text, Key)
text = E(cipher, Key)
```

Good

- Fast, intuitive (password-like), small keys

Bad

- Must share a key *(privately!)* before talking

Applications

- Bank ATM links, secure telephones

Public-Key Cryptography

Concept: *asymmetric* cipher (aka "magic")

```
cipher = E(text, Key1)
text = D(cipher, Key2)
```

Keys are *different*

- Generate *key pair*
- Publish "public key"
- Keep "private key" *very* secret

Public Key Encryption

Sending secret mail

- Locate receiver's public key
- Encrypt mail with it
- Nobody can read it
  - *Not even you!*

Receiving secret mail

- Decrypt mail with your private key
  - No matter who sent it

Public Key Signatures

Write a document

Encrypt it with your private key

- Nobody else can do that

Transmit plaintext *and ciphertext* of document

Anybody can decrypt with your public key

- If they match, the sender knew your private key
  - ...sender was you, more or less

(really: send E(hash(msg), K_p))

Public Key Cryptography

Good

- No need to privately exchange keys

Bad

- Algorithms are slower than private-key
- Must trust key directory

Applications

- Secret mail, signatures

Comparison

Private-key algorithms

- Fast crypto, small keys
- *Secret-key-distribution problem*

Public-key algorithms

- "Telephone directory" key distribution
- Slow crypto, *keys too large to memorize*

Can we get the best of both?

Kerberos

Goals

- Use fast private-key encryption
- Require users to remember one *small* key
- Authenticate & encrypt for N users, M servers

Problem

- Private-key encryption requires shared key to communicate
- Can't deploy & use system with NxM keys!

Intuition

- *Trusted third party* knows single key of *every* user, server
- Distributes temporary keys to (user,server) on demand

Not Really Kerberos

Client contacts server with a *ticket*

- Specifies *identity* of holder
  - Server will use identity for access control checks
- Specifies *session key* for encryption
  - Server will decrypt messages from client
  - Also provides authentication – only client can encrypt with that key
- Specifies time of issuance
  - Ticket “times out”, client must re-prove it knows its key

Not Really Kerberos

Ticket format

- Ticket={client,time,$K_{session}$}K_s
  - Notation: client, time, session key; DES-encrypted with server's secret key

Observations

- Server knows K_s, can decrypt & understand the ticket
- Clients can't fake tickets, since they don't know K_s
- Session key is provided to server via encrypted channel
  - Eavesdroppers can't learn session key
  - Client-server communication will be secure

How do clients get tickets?

- Only server & Kerberos Distribution Center know K_s...

Not Really Kerberos

Client sends to Key Distribution Center

- "I want a ticket for the printing service"
- {client, server, time}

KDC sends client two things

- $\{K_{session}, server, time\}K_c$
  - Client can decrypt this to learn session key
  - Client knows expiration time contained in ticket
- $Ticket = \{client, time, K_{session}\}K_s$
  - Client cannot decrypt ticket
  - Client *can* transmit ticket to server as opaque data

Not Really Kerberos

Results (client)

- Client has session key for encryption
  - Can trust that only desired server knows it

Results (server)

- Server knows identity of client
- Server knows how long to trust that identity
- Server has session key for encryption
  - Data which decrypt meaningfully must be from that client

Not Really Kerberos

Results (architecture)

- N users, M servers
- System has N+M keys
  - Like a public-key crypto system
  - But fast private-key ciphers are used
- Each entity remembers only one (small) key
  - “Single-sign on”: one password per user

Any weakness?

Securing a Kerberos Realm

KDC (Kerberos Distribution Center)

- Knows *all* keys in system
- Single point of failure
  - If it's down, clients can't get tickets to contact more servers...
- Single point of *compromise*
- *Very* delicate to construct & deploy
  - Turn off most Internet services
  - Maybe boot from read-only media
  - Unwise to back up key database to “shelf full of tapes”

Typical approach

- Multiple instances of server (master/slave)
- Deployed in *locked boxes* in (multiple) machine rooms

SSL

Goals

- **Fast, secure commnication**
- **Any client can contact any server on planet**

Problems

- **There is no single trusted party for the whole planet**
  - **Can't use Kerberos approach**
- **Solution: public-key cryptography?**
  - **Issue: public key algorithms are slow**
  - ***Big problem: there is no global public-key directory***

SSL Approach (Wrong)

Approach

- Use private-key/symmetric encryption for speed
- Swap symmetric session keys via public-key crypto
  - Temporary random session keys similar to Kerberos

Steps

- Client looks up server's public key in global directory
- Client generates random DES session key
- Client encrypts session key using server's RSA public key
- Now client, server both know session key
- Client knows it is talking to the desired server
  - After all, nobody else can do the decrypt...

SSL Approach (Wrong)

Problem

- *There is no global key directory*
- Would be a single point of compromise
  - False server keys enable server spoofing
- If you had a copy of one it would be out of date
  - Some server would be deployed during your download

Approach

- Replace global directory with *chain of trust*
- Servers present their own keys to clients
- Keys are signed by “well-known” certifiers

Not SSL

Server "certificate"

- "To whom it may concern, whoever can *decrypt* messages *encrypted* with public key AAFD01234DE34BEEF997C is www.cmu.edu"

Protocol operation

- Client calls server, requests certificate
- Server sends certificate
- Client generates private-key *session key*
- Client sends $\{K_{session}\}K_{server}$ to server
- If server can decrypt and use $K_{session}$, it must be legit

Any problem...?

SSL Certificates

How did we know to trust that certificate?

Certificates are signed by *certificate authorities*

- "Whoever can *decrypt* messages *encrypted* with public key AAFD01234DE34BEEF997C is www.cmu.edu
  - Signed, Baltimore CyberTrust
    - » SHA-1 hash of statement: 904ffa3bb39348aas
    - » Signature of hash: 433432af33551a343c143143fd11

Certificate verification

- Look up public key of Baltimore CyberTrust in global directory...oops!

SSL Certificates

How did we know to trust the server's certificate?

- Certificates signed by *certificate authorities*
- Browser vendor ships CA public keys in browser
  - Check your browser's security settings, see who you trust!
- "Chain of trust"
  - Mozilla.org certifies Baltimore Cybertrust
  - Baltimore Cybertrust certifies www.cmu.edu

PGP

Goal

- "Pretty Good Privacy" for the masses
- Without depending on a central authority

Approach

- Users generate public-key key pairs
- Public keys stored "on the web" (pgpkeys.mit.edu)
  - Global directory (untrusted, like a whiteboard)
- We have covered how to send & receive secret e-mail

Problem

- How do I *trust* a public key I get from "on the web"?

“On the Web”

PGP key server protocol

- ???: Here is de0u@andrew.cmu.edu's latest public key!
  - Server: “Great, I'll provide it when anybody asks!”
- Rahul: What is de0u@andrew.cmu.edu's public key?
  - Server: Here are 8 possibilities...decide which to trust!

How do I *trust* a public key I get “from the web”?

- “Certificate Authority” approach has issues
  - They typically charge $50-$1000 per certificate *per year*
  - They are businesses...governments can lean on them
    - » ...to present false keys...
    - » ...to delete your key from their directory...
    - » ...to refuse to sign your key...

PGP

"*Web* of trust"

- Dave and Bruce swap public keys ("key-signing party")
- Bruce signs Dave's public key
  - Publishes signature on one or more web servers
- Rahul and Bruce swap public keys (at lunch)

Using the web of trust

- Rahul fetches Dave's public key
  - Verifies Bruce's signature on it
- Rahul can safely send secret mail to Dave
- Rahul can verify digital signatures from Dave

PGP “key rings”

Private key ring

- All of your private keys
- Each encrypted with a “pass phrase”
  - Should be longer, more random than a password
  - If your private keys leak out, you can't easily change them

Public key ring

- Public keys of various people
  - Each has one or more signatures
  - Some are signed by you – your PGP will use without complaint

PGP Messages

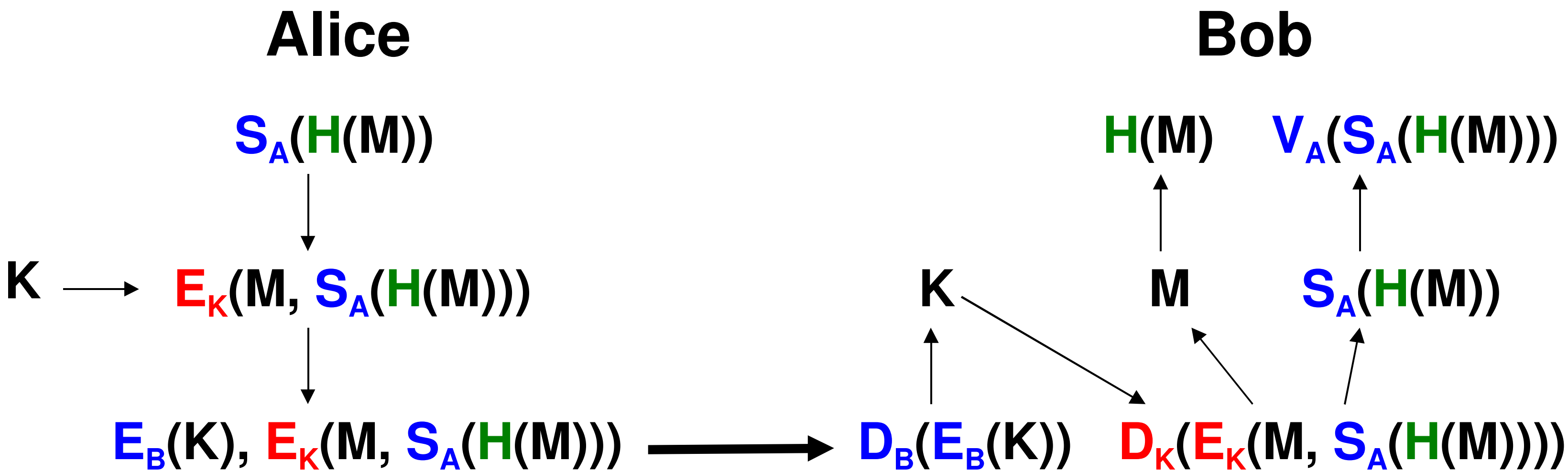
Message goals

- Decryptable by multiple people (recipients of an e-mail)
- Large message bodies decryptable quickly
- Message size not proportional to number of receivers

Message structure

- One message body, encrypted with a symmetric cipher
  - Using a random “session” key
- N key packets
  - Session key public-key encrypted with one recipient's key

Not PGP



Note: on this slide, E_K(a, b) means ..."a and b"...

Biometrics

Concept

- Tie authorization to ***who you are***
  - Not what you know – can be copied
- Hard to impersonate a retina
  - Or a fingerprint

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Right?

What about gummy bears?

Summary

Many threats

Many techniques

“The devil is in the details”

Just because it “works” doesn't mean it's right!

Open algorithms, open source

Further Reading

Kerberos: An Authentication Service for Computer Networks

- B. Clifford Neuman, Theodore Ts'o
- USC/ISI Technical Report ISI/RS-94-399

Impact of Artificial "Gummy" Fingers on Fingerprint Systems

- Matsumoto et al
- http://cryptome.org/gummy.htm