

15-410

“...What about gummy bears?...”

Security Applications Apr. 25, 2005

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PGP diagram shamelessly stolen
from 15-441

Synchronization

P4 Hand-in directories have been created

- Please check 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 list works for *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 $E(\text{time}, \text{key})$
 - 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 $E(\text{hash}(\text{msg}), K_p)$)

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

- Authenticate & encrypt for N users, M servers
- Fast private-key encryption
- Users remember one *small* key

Problem

- Private-key encryption requires shared key to communicate
- Can't deploy & use system with $N \times M$ 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

- $\{K_{\text{session}}, \text{server}, \text{time}\}_{K_c}$
 - Client can decrypt this to learn session key
 - Client knows expiration time contained in ticket
- Ticket = $\{\text{client}, \text{time}, K_{\text{session}}\}_{K_s}$
 - 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 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 machine room

SSL

Goals

- Fast, secure communication
- 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?
 - Problem: 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 $\{K_{\text{session}}\}_{K_{\text{server}}}$ 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 that 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 the web”?

“On the Web”

PGP key server protocol

- ????: Here is de0u@andrew.cmu.edu's latest public key!
 - Server: “Looks good to me!”
- Claire: 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
- Claire and Bruce swap public keys (at lunch)

Using the web of trust

- Claire fetches Dave's public key
 - Verifies Bruce's signature on it
- Claire can safely send secret mail to Dave
- Claire 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

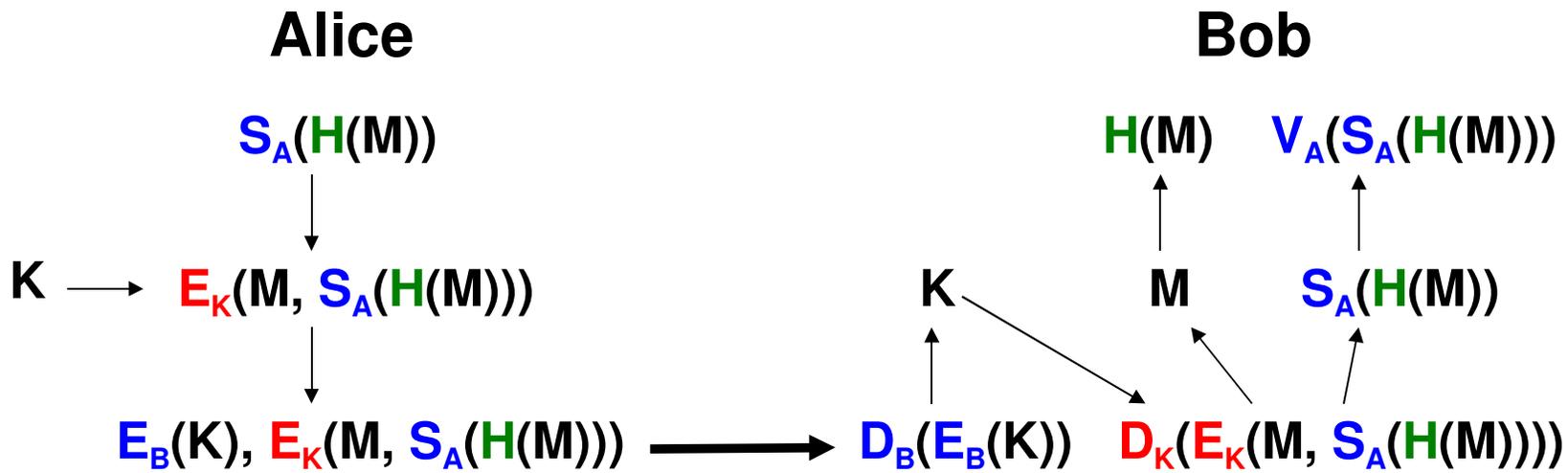
Message goals

- Decryptable by multiple people (recipients of an e-mail)
- Large message bodies decryptable quickly
- 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



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>