Cryptographic Keys
CS 136
Computer Security
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Outline

- Properties of keys
- Key management
- Key servers
- Certificates

Introduction

have a strong security, description -> if someone gets your public key cryptography

- It doesn't matter how strong your encryption algorithm is
- Or how secure your protocol is
- If the opponents can get hold of your keys, your security is gone
- Proper use of keys is crucial to security in computing systems

Properties of Keys

trade-off: speed vs. security

- Length — number of bits in the key — the longer the key, there are more possible combinations
- Randomness — use a good random number generator to make it hard for attackers to break your key
- Lifetime — life span of the key
- Secrecy

perfect forward secrecy: if attacker finds one bit of previous keys, it doesn't have relation to any of the previous bits, no pattern that you can work off of

the compromise of one session key is not going to screw the others

Key Length

- If your cryptographic algorithm is otherwise perfect, its strength depends on key length
- Since the only attack is a brute force attempt to discover the key
- The longer the key, the more brute force required

Are There Real Costs for Key Length?

- Generally, more bits is more secure
- Why not a whole lot of key bits, then?
- Some encryption done in hardware
  - More bits in hardware costs more
- Some software encryption slows down as you add more bits, too
  - Public key cryptography especially
- Some algorithms have defined key lengths only
- If the attack isn't brute force, key length might not help

Key Randomness

key generation should be random

- Brute force attacks assume you chose your key at random you need a good random number generator
- If attacker learns how you chose your key
  - He can reduce brute force costs
- How good is your random number generator?

there are patterns in the rand function (based on time)
there are other functions that you could use

Generating Random Keys

- Well, don't use `rand()`[1]
- The closer the method chosen approaches true randomness, the better
- But, generally, don't want to rely on exotic hardware

approach true for all expressions that are true

- True randomness is not essential
  - Need same statistical properties
  - And non-reproducibility

need some stat properties
and non-reproducable

rand() is a bad idea!!!

[1]See http://eprint.iacr.org/2013/338.pdf for details

Cryptographic Methods

hasing algorithm can help us generate a random number

every time passing into hash, we get different output - it will unpredictable

- Start with a random number
- Use a cryptographic hash on it
- If the cryptographic hash is a good one, the new number looks pretty random
- Produce new keys by hashing old ones
- Depends on strength of hash algorithm
- Falls apart if any key is ever broken
  - Doesn't have *perfect forward secrecy*

can't give someone else the key

perfect forward secrecy 0 prerpprp dd d

implies that there are no dependency

Perfect Forward Secrecy

- A highly desirable property in a cryptosystem
- It means that the compromise of any one session key will not compromise any other
  - E.g., don't derive one key from another using a repeatable algorithm
- Keys do get divulged, so minimize the resulting damage

cosmic ray hardware - approximates truly random behavior

between time he typed first scene and last

Random Noise

- Observe an event that is likely to be random
  - Physical processes (cosmic rays, etc.)
  - Real world processes (variations in disk drive delay, keystroke delays, etc.)
- Assign bit values to possible outcomes
- Record or generate them as needed
- More formally described as *gathering entropy*

keystroke delay and fast typing to generate a lot of entropy

- Keys derived with proper use of randomness have good perfect forward secrecy

On Users and Randomness

- Some crypto packages require users to provide entropy
  - To bootstrap key generation or other uses of randomness

entropy is not very good because there are bias

- Users do this badly (often very badly)
- They usually try to do something simple
  - And not really random
- Better to have crypto package get its own entropy

Don't Go Crazy on Randomness

- Make sure it's non-reproducible
  - So attackers can't play it back
- Make sure there aren't obvious patterns
- Attacking truly unknown patterns in fairly random numbers is extremely challenging
  - They'll probably mug you, instead

avoid trying to make some patterns

Key Lifetime

gives attackers more time to figure out a solution;

- If a good key's so hard to find,
  - Why every change it?
- How long should one keep using a given key?

why change your keys?
exp shows the longer you use your key
the higher chance that it is compromised

also, the more use of key, the more
data that can be read through

Why Change Keys?

- Long-lived keys more likely to be compromised
- The longer a key lives, the more data is exposed if it's compromised
- The longer a key lives, the more resources opponents can (and will) devote to breaking it
- The more a key is used, the easier the cryptanalysis on it
- **A secret that cannot be readily changed should be regarded as a vulnerability**

don't put keys and pasw

Practicalities of Key Lifetimes

dont need to change thd password

- In some cases, changing keys is inconvenient
  - E.g., encryption of data files
- Keys used for specific communications sessions should be changed often
  - E.g., new key for each phone call
- Keys used for key distribution can't be changed too often

generate a brand new key for every instant esesagin

the colder it is, the slower it shuts down
the attacker can examine your computer

keys are stored in very obscure places, be sure that it is deleted somewhere
ex. stored in cache in a system, someone can hack it

Destroying Old Keys

- Never keep a key around longer than necessary
  - Gives opponents more opportunities
- Destroy keys securely
  - For computers, remember that information may be in multiple places
    - Caches, virtual memory pages, freed file blocks, stack frames, etc.
  - Real modern attacks based on finding old keys in unlikely places

Key Storage

need to make sure you oknkey; store it somewhere saeol

- The flip side of destroying keys –
  - You'd better be sure you don't lose a key while you still need it
- Without the key, you can't read the encrypted data
  - Kind of a bummer, if you wanted to
- Key storage is one approach

RansomWare - encrypts all the files in victim's computer

What Is Key Storage?

ex. randomware - an attacker encrypts on your data, you have to pay

- Saving a copy of a cryptographic key "somewhere else"
- Securely store a key in some safe place
- If you lose it accidentally, get it back from storage location
- Prevents encrypted data from becoming unreadable

you can put in a flash drive / separate machine, stack eeb==ver

Where Should You Store Keys?

- Must not be accessible to an attacker
  - Don't want him to get hold of all your keys
  - Don't want them readily available if your machine is hacked
- But relatively accessible when needed
- Usually on a separate machine

How Do You Get Keys There?

be careful when sending keys over the network
transport it to something called a key server
make sure there's a high degree of associativity
—> must be a lot of channels

- And back
- Each new key must be transported to the key server
- Not much saved if transport mechanism is compromised
- Need carefully designed/implemented mechanism for moving keys

Key Secrecy

- Seems obvious
- Of course you keep your keys secret
- However, not always handled well in the real world
- Particularly with public key cryptography

Some Problems With Key Sharing

- Private keys are often shared
  - Same private key used on multiple machines
  - For multiple users
  - Stored in "convenient" places
  - Perhaps backed up on tapes in plaintext form

private keys often shared among companies
but private keys should only be for you

Why Do People Do This?

- For convenience
- To share expensive certificates
- Because they aren't thinking clearly
- Because they don't know any better
- A recent example:
  - RuggedCom's Rugged Operating System for power plant control systems
  - Private key embedded in executable

To Make It Clear,

- **PRIVATE KEYS ARE PRIVATE!** private keys are
- They are for use by a single user
- They should never be shared or given away
- They must never be left lying around in insecure places
  - Widely distributed executables are insecure
  - Just because it's tedious to decipher executables doesn't mean can't be done
- The entire security of PK systems depends on the secrecy of the private key!

Key Management

- Choosing long, random keys doesn't do you any good if your clerk is selling them for $10 a pop at the back door
- Or if you keep a plaintext list of them on a computer on the net whose root password is "root"
- Proper key management is crucial

Desirable Properties in a Key Management System

- Secure
- Fast
- Low overhead for users not too costly
- Scaleable
- Adaptable
  - Encryption algorithms
  - Applications handle any type of application
  - Key lengths

we want key length to be longer because we wil have more options

Users and Keys

- Where are a user's keys kept?
- Permanently on the user's machine?
  - What happens if the machine is cracked?
- But people can't remember random(ish) keys
  - Hash keys from passwords/passphrases?
- Keep keys on smart cards?
- Get them from key servers?

Key Servers

systems that specialize in storing and keeping keys

- Special machines whose task is to generate, store and manage keys
- Generally for many parties
- Possibly Internet-wide
- Obviously, key servers are highly trusted

Security of Key Servers

- The key server is the cracker's holy grail
  - If they break the key server, everything else goes with it
- What can you do to protect it?

Security for Key Servers

- Don't run anything else on the machine
- Use extraordinary care in setting it up and administering it
- Watch it carefully

don't run anlything else on the key serever

- Use a key server that stores as few keys permanently as possible
  - At odds with need for key storage
- Use a key server that handles revocation and security problems well

Single Machine Key Servers

- Typically integrated into the web browser
  - Often called *key chains* or *password vaults*

lastpass or one passwords

- Stores single user's keys or passwords for various web sites
- Usually protected with an overall access key
- Obvious, encrypted versions stored on local disk

Security Issues for Single Machine Key Servers

- Don't consider one that doesn't store keys encrypted
- Issues of single sign-on
  - If computer left unattended
  - In case of remote hacking
    - Anything done by your web browser is "you"

you are the one who can control the keys

you have your own server machines

Local Key Servers

- Can run your own key server machine
  - Stores copies of all keys you use
- Possibly creates keys when needed
- Uses careful methods to communicate with machines using it
- E.g., Oracle Key Manager 3
  - Primarily intended for tapes

Key Storage Services

- Third party stores your keys for you
  - In encrypted form they can't read
- ANSI standard (X9.24) describes how third party services should work
- Not generally popular
- HyperSafe Remote Key System is one example
- Variants may become important for cloud computing

used everywhere - authentication is the ability to determine which party belongs to which certificate

Certificates

- A ubiquitous form of authentication
- Generally used with public key cryptography

bootstrap public key crypree

- A signed electronic document proving you are who you claim to be
- Often used to help distribute other keys

bootstrap - use your original foundation to build on itself

certificates are bootstrap of public key cryptography

We have to tie a website with a public key that is actually Amazon.com; only Amazon has the private key, so they can encrypt sensitive information

Public Key Certificates

certifies someone as a member of a trusted authority

- The most common kind of certificate
- Addresses the biggest challenge in widespread use of public keys
  - How do I know whose key it is?
- Essentially, a copy of your public key signed by a trusted authority
- Presentation of the certificate alone serves as authentication of your public key

VeriSign - they help us do digital signatures

authority: someone who is monitoring key distribution

Implementation of Public Key Certificates

- Set up a universally trusted authority
- Every user presents his public key to the authority

Amazon will request for a certificate for their public key
we want to confirm that someone's public key is considered to be authorized

- The authority returns a certificate
  - Containing the user's public key signed by the authority's private key
- In essence, a special type of key server

no need to go to verisign server to check this, you already have the authenticity because you already have a public key to check it
done offline in the past

Checking a Certificate

- Every user keeps a copy of the authority's public key
- When a new user wants to talk to you, he gives you his certificate
- Decrypt the certificate using the authority's public key
- You now have an authenticated public key for the new user
- Authority need not be checked on-line

Scaling Issues of Certificates

- If there are 1-2 billion Internet users needing certificates, can one authority serve them all?
- Probably not
- So you need multiple authorities
- Does that mean everyone needs to store the public keys of all authorities?

I can only use a certificate if I had the public key of whoever signed it.

Certification Hierarchies

an authority who we all trust; multiple signing authorities for all websites we go to;
do recursive operation: multiple public keys, multiple signatures; in addition to his signature verifying that this is Amazon.com, we also have a universal authority.

- Arrange certification authorities hierarchically
- Single authority at the top produces certificates for the next layer down
- And so on, recursively

Using Certificates From Hierarchies

recursively go down at the signature, and go to the one I care about

- I get a new certificate
- I don't know the signing authority
- But the certificate also contains that authority's certificate
- Perhaps I know the authority who signed this authority's certificate

single authority at the top produce certificates all the way down

Extracting the Authentication

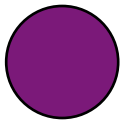
- Using the public key of the higher level authority,
  - Extract the public key of the signing authority from the certificate

in the future, I already have your public key; subseqent times I can just use the public key I already have

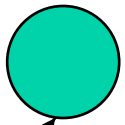
- Now I know his public key, and it's authenticated
- I can now extract the user's key and authenticate it

A Example

Alice gets a message with a certificate



higher level certification authority



Then she uses
to check 

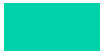
Give me a certificate saying that I'm 

Should Alice believe that he's really  ?

So she uses 
to check

Alice has never heard of
But she has heard of 

yellow guy's s signature is proved from the purple signature

How can  prove who he is?

Certification Hierarchies Reality

- Not really what's used
  - For the most part
- Instead, we rely on large numbers of independent certifying authorities
  - Exception is that each of them may have internal hierarchy
- Essentially, a big list
- Is this really better?

need a lot of public keys just sitting around
ex. when you download a browser, you will see a bunch of public keys

150 public keys - from Firewall
you just have to believe them

Certificates and Trust

- Ultimately, the point of a certificate is to determine if something is trusted
  - Do I trust the request enough to perform some financial transaction?
- So, Trustysign.com signed this certificate
- How much confidence should I have in the certificate?

transitive trust happening here

Potential Problems in the Certification Process

- What measures did Trustysign.com use before issuing the certificate?
- Is the certificate itself still valid?
- Is Trustysign.com's signature/ certificate still valid?
- Who is trustworthy enough to be at the top of the hierarchy?

did things to verify that the person asking for the certificates knows who these ppl are

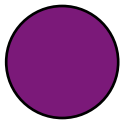
Trustworthiness of Certificate Authority

- How did Trustysign.com issue the certificate?
- Did it get an in-person sworn affidavit from the certificate's owner?
- Did it phone up the owner to verify it was him?
- Did it just accept the word of the requestor that he was who he claimed to be?
- Has authority been compromised?

What Does a Certificate Really Tell Me?

- That the certificate authority (CA) tied a public/private key pair to identification information
- Generally doesn't tell me why the CA thought the binding was proper
- I may have different standards than that CA

Showing a Problem Using the Example

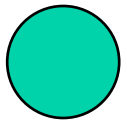


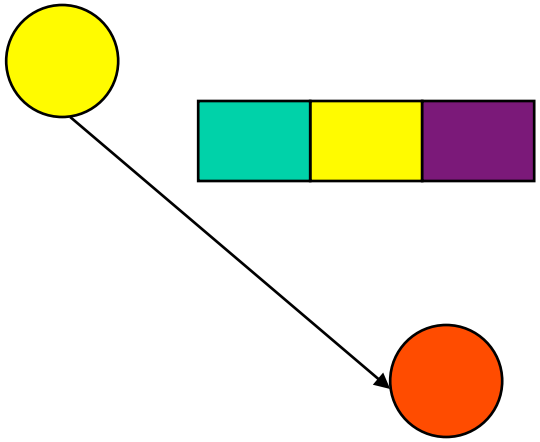
Alice likes how verifies identity

But is she equally happy with how verifies identity?

Does she even know how verifies identity?

What if uses 's lax policies to pretend to be ?





Another Big Problem

- Things change
  - E.g., recent compromise of Adobe private keys
- One result of change is that what used to be safe or trusted isn't any more
- If there is trust-related information out in the network, what will happen when things change?

Revocation

- Revok/take it away

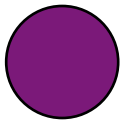
- A general problem for keys, certificates, access control lists, etc.
- How does the system revoke something related to trust?

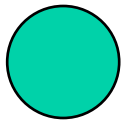
configure browser becfore it accepts aat cerficate list

- In a network environment
- Safely, efficiently, etc.
- Related to revocation problem for capabilities

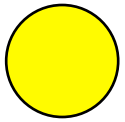
Revisiting Our Example

Someone discovers that  has obtained a false certificate for 

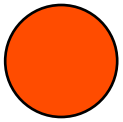




How does Alice make sure that she's not accepting  's false certificate?



red has bogus certificate



Realities of Certificates

- Most OSes come with set of "pre-trusted" certificate authorities
- System automatically processes (i.e., trusts) certificates they sign
- Usually no hierarchy
- If not signed by one of these, present it to the user
  - Who always accepts it . . .

An Example

there are few hierarchies because there's more overhead if there are more dependency

- Firefox web browser
- Makes extensive use of certificates to validate entities
  - As do all web browsers
- Comes preconfigured with several certificate authorities
  - Over 200 of them

Firefox Preconfigured Certificate Authorities

- Some you'd expect:
  - Microsoft, RSA Security, Verisign, etc.
- Some you've probably never heard of:
    - Unizeto Sp. z.o.o., Netlock Halozatbiztonsagi Kft.,Chungwa Telecom Co. Ltd.

The Upshot

- If Netlock Halozatbiztonsagi Kft. says someone's OK, I trust them
  - I've never heard of Netlock Halozatbiztonsagi Kft.
  - I have no reason to trust Netlock Halozatbiztonsagi Kft.
  - But my system's security depends on them

The Problem in the Real World

- In 2011, a Dutch authority (DigiNotar) was compromised DigiNotar's private keys were gtaken awayf from hackers
- Attackers generated lots of bogus certificates signed by DigiNotar
  - "Properly" signed by that authority
  - For popular web sites
- Until compromise discovered, everyone trusted them

Effects of DigiNotar Compromise

- Attackers could transparently redirect users to fake sites
  - What looked like Twitter was actually attacker's copycat site
- Allowed attackers to eavesdrop without any hint to users man in the middle attas
- Apparently used by authorities in Iran to eavesdrop on dissidents

How Did the Compromise Occur?

sad thing is, a bunch of people don't even know they were using it

- DigiNotar had crappy security
  - Out-of date antivirus software
  - Poor software patching
  - Weak passwords
  - No auditing of logs
  - Poorly designed local network
- A company providing security services paid little attention to security

But how were you supposed to know that?

A Firefox Solution

- Certificate key pinning
- Code into the browser the "right" signing authority for particular sites
- So a certificate for Google signed by, say, DigiNotar gets rejected
- Currently only for a couple of big name web sites

a broswer wil certificate pinning, we will know that whoeever signed the ecertificate for google will be allowed to. This means that we can scan and get rid of bogus companies

Another Practicality

- Certificates have expiration dates
  - Important for security
  - Otherwise, long-gone entities would still be trusted
- But perfectly good certificates also expire
  - Then what?

The Reality of Expired Certificates

- When I hear my server's certificate has expired, what do I do?
  - I trust it anyway
  - After all, it's my server
- But pretty much everyone does that
  - For pretty much every certificate
- Not so secure

The Core Problem With Certificates

- Anyone can create some certificate
- Typical users have no good basis for determining whose certificates to trust
  - They don't even really understand what they mean
- Therefore, they trust almost any certificate

Should We Worry About Certificate Validity?

- Starting to be a problem
  - Stuxnet is one example
  - Compromise of DigiNotar and Adobe also
  - Increasing incidence of improper issuance, like Verisign handing out Microsoft certificates
- Not the way most attackers break in today
- With all their problems, still not the weakest link
  - But now being exploited, mostly by most sophisticated adversaries

Heartbleed and Certificates

- OpenSSL relies on certificates and private keys for key distribution
- If Heartbleed compromised those, then serious problems
  - Just like DigiNotar, but for all certificate authorities at once
- Current evidence suggests Heartbleed can expose certificates
  - No evidence it ever did, but . . .
  - So we may need to change all certificates

Should I Trust Crypto At All?

- Recent revelations suggest that the NSA can read many encrypted messages
- Experts think they mostly have compromised key selection/handling
  - Rather than the crypto itself
- But also possible that particular implementations have been "bugged"

Some Practical Advice on Crypto

- From Bruce Schneier, who should know
- **Use crypto to protect your data**
- **Trust the math, not the program**
- **Be suspicious of commercial crypto**
  - **Especially from big companies**
- **Use public-domain crypto whenever possible**

  anything open source cryptography; use RSA, AES, things that are already established well
  - **Especially standards requiring interoperability**