CSci 4271W
Development of Secure Software Systems
Day 24: Protocols in practice

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## Outline



## Anti-pattern: "oracle"

- Any way a legitimate protocol service can give a capability to an adversary
- Can exist whenever a party decrypts, signs, etc.
- "Padding oracle" was an instance of this at the implementation level

## Outline



## Public key authenticity

- Public keys don't need to be secret, but they must be right
- Wrong key $\rightarrow$ can't stop middleperson
- So we still have a pretty hard distribution problem

## Symmetric key servers

- Users share keys with server, server distributes session keys
- Symmetric key-exchange protocols, or channels
- Standard: Kerberos
- Drawback: central point of trust

## Certificates

- A name and a public key, signed by someone else
  - $C_A = \text{Sign}_S(A, K_A)$
- Basic unit of transitive trust
- Commonly use a complex standard "X.509"

## Certificate authorities

- "CA" for short: entities who sign certificates
- Simplest model: one central CA
- Works for a single organization, not the whole world

## Web of trust

- Pioneered in PGP for email encryption
- Everyone is potentially a CA: trust people you know
- Works best with security-motivated users
  - Ever attended a key signing party?

## CA hierarchies

- Organize CAs in a tree
- Distributed, but centralized (like DNS)
- Check by follow a path to the root
- Best practice: sub CAs are limited in what they certify

## PKI for authorization

- Enterprise PKI can link up with permissions
- One approach: PKI maps key to name, ACL maps name to permissions
- Often better: link key with permissions directly, name is a comment

## The revocation problem

- How can we make certs "go away" when needed?
- Impossible without being online somehow

1. Short expiration times
2. Certificate revocation lists
3. Certificate status checking

## Outline

Cryptographic protocols, cont'd

Key distribution and PKI

Announcements intermission

SSH

SSL/TLS

More causes of crypto failure

## Project 1 status

- We've reduced the required number of vulnerabilities to 2
  - Extra credit available for 3 or more
- Regular due date is still Monday night
- Please continue non-spoiler public discussions on Piazza

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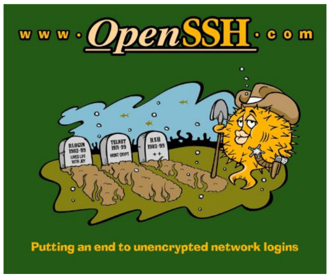
## Short history of SSH

- Started out as freeware by Tatu Ylönen in 1995
- Original version commercialized
- Fully open-source OpenSSH from OpenBSD
- Protocol redesigned and standardized for "SSH 2"

## OpenSSH t-shirt




## SSH host keys

- Every SSH server has a public/private keypair
- Ideally, never changes once SSH is installed
- Early generation a classic entropy problem
  - Especially embedded systems, VMs

## Authentication methods

- Password, encrypted over channel
- `.shosts`: like `.rhosts`, but using client host key
- User-specific keypair
  - Public half on server, private on client
- Plugins for Kerberos, PAM modules, etc.

## Old crypto vulnerabilities

- 1.x had only CRC for integrity
  - Worst case: when used with RC4
- Injection attacks still possible with CBC
  - CRC compensation attack
- For least-insecure 1.x-compatibility, attack detector
- Alas, detector had integer overflow worse than original attack

## Newer crypto vulnerabilities

- IV chaining: IV based on last message ciphertext
  - Allows chosen plaintext attacks
  - Better proposal: separate, random IVs
- Some tricky attacks still left
  - Send byte-by-byte, watch for errors
  - Of arguable exploitability due to abort
- Now migrating to CTR mode

## SSH over SSH

- SSH to machine 1, from there to machine 2
  - Common in these days of NATs
- Better: have machine 1 forward an encrypted connection

1. No need to trust 1 for secrecy
2. Timing attacks against password typing

## SSH (non-)PKI

- When you connect to a host freshly, a mild note
- When the host key has changed, a large warning

```
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
@    WARNING: REMOTE HOST IDENTIFICATION HAS CHANGED!    @
@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@@
IT IS POSSIBLE THAT SOMEONE IS DOING SOMETHING NASTY!
Someone could be eavesdropping on you right now
(man-in-the-middle attack)!
It is also possible that a host key has just been changed.
```

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## SSL/TLS

- Developed at Netscape in early days of the public web
  - Usable with other protocols too, e.g. IMAP
- SSL 1.0 pre-public, 2.0 lasted only one year, 3.0 much better
- Renamed to TLS with RFC process
  - TLS 1.0 improves SSL 3.0
- TLS 1.1 and 1.2 in 2006 and 2008, only gradual adoption

## IV chaining vulnerability

- TLS 1.0 uses previous ciphertext for CBC IV
- But, easier to attack in TLS:
  - More opportunities to control plaintext
  - Can automatically repeat connection
- "BEAST" automated attack in 2011: TLS 1.1 wakeup call

## Compression oracle vuln.

- Compr$(S \parallel A)$, where $S$ should be secret and $A$ is attacker-controlled
- Attacker observes ciphertext length
- If $A$ is similar to $S$, combination compresses better
- Compression exists separately in HTTP and TLS

## But wait, there's more!

- Too many vulnerabilities to mention them all in lecture
- Kaloper-Meršinjak et al. have longer list
  - "Lessons learned" are variable, though
- Meta-message: don't try this at home

## HTTPS hierarchical PKI

- Browser has order of 100 root certs
  - Not same set in every browser
  - Standards for selection not always clear
- Many of these in turn have sub-CAs
- Also, "wildcard" certs for individual domains

## Hierarchical trust?

- No. Any CA can sign a cert for any domain
- A couple of CA compromises recently
- Most major governments, and many companies you've never heard of, could probably make a `google.com` cert
- Still working on: make browser more picky, compare notes

## CA vs. leaf checking bug

- Certs have a bit that says if they're a CA
- All but last entry in chain should have it set
- Browser authors repeatedly fail to check this bit
- Allows any cert to sign any other cert

## MD5 certificate collisions

- MD5 collisions allow forging CA certs
- Create innocuous cert and CA cert with same hash
  - Requires some guessing what CA will do, like sequential serial numbers
  - Also 200 PS3s
- Oh, should we stop using that hash function?

## CA validation standards

- CA's job to check if the buyer really is `foo.com`
- Race to the bottom problem:
  - CA has minimal liability for bad certs
  - Many people want cheap certs
  - Cost of validation cuts out of profit
- "Extended validation" (green bar) certs attempt to fix

## HTTPS and usability

- Many HTTPS security challenges tied with user decisions
- Is this really my bank?
- Seems to be a quite tricky problem
  - Security warnings often ignored, etc.

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## Random numbers and entropy

- Cryptographic RNGs use cipher-like techniques to provide indistinguishability
- But rely on truly random seeding to stop brute force
  - Extreme case: no entropy $\rightarrow$ always same "randomness"
- Modern best practice: seed pool with 256 bits of entropy
  - Suitable for security levels up to $2^{256}$

## Netscape RNG failure

- Early versions of Netscape SSL (1994-1995) seeded with:
  - Time of day
  - Process ID
  - Parent process ID
- Best case entropy only 64 bits
  - (Not out of step with using 40-bit encryption)
- But worse because many bits guessable

## Debian/OpenSSL RNG failure (1)

- OpenSSL has pretty good scheme using `/dev/urandom`
- Also mixed in some uninitialized variable values
  - "Extra variation can't hurt"
- From modern perspective, this was the original sin
  - Remember undefined behavior discussion?
- But had no immediate ill effects

## Debian/OpenSSL RNG failure (2)

- Debian maintainer commented out some lines to fix a Valgrind warning
  - "Potential use of uninitialized value"
- Accidentally disabled most entropy (all but 16 bits)
- Brief mailing list discussion didn't lead to understanding
- Broken library used for ~2 years before discovery

## Detected RSA/DSA collisions

- 2012: around 1% of the SSL keys on the public net are breakable
  - Some sites share complete keypairs
  - RSA keys with one prime in common (detected by large-scale GCD)
- One likely culprit: insufficient entropy in key generation
  - Embedded devices, Linux `/dev/urandom` vs. `/dev/random`
- DSA signature algorithm also very vulnerable

## Side-channel attacks

- Timing analysis:
  - Number of 1 bits in modular exponentiation
  - Unpadding, MAC checking, error handling
  - Probe cache state of AES table entries
- Power analysis
  - Especially useful against smartcards
- Fault injection
- Data non-erasure
  - Hard disks, "cold boot" on RAM

## WEP "privacy"

- First WiFi encryption standard: Wired Equivalent Privacy (WEP)
- F&S: designed by a committee that contained no cryptographers
- Problem 1: note "privacy": what about integrity?
  - Nope: stream cipher + CRC = easy bit flipping

## WEP shared key

- Single key known by all parties on network
- Easy to compromise
- Hard to change
- Also often disabled by default
- Example: a previous employer

## WEP key size and IV size

- Original sizes: 40-bit shared key (export restrictions) plus 24-bit IV = 64-bit RC4 key
  - Both too small
- 128-bit upgrade kept 24-bit IV
  - Vague about how to choose IVs
  - Least bad: sequential, collision takes hours
  - Worse: random or everyone starts at zero

## WEP RC4 related key attacks

- Only true crypto weakness
- RC4 "key schedule" vulnerable when:
  - RC4 keys very similar (e.g., same key, similar IV)
  - First stream bytes used
- Not such a problem for other RC4 users like SSL
  - Key from a hash, skip first output bytes

## New problem with WPA (CCS'17)

- Session key set up in a 4-message handshake
- Key reinstallation attack: replay #3
  - Causes most implementations to reset nonce and replay counter
  - In turn allowing many other attacks
  - One especially bad case: reset key to 0
- Protocol state machine behavior poorly described in spec
  - Outside the scope of previous security proofs

## Trustworthiness of primitives

- Classic worry: DES S-boxes
- Obviously in trouble if cipher chosen by your adversary
- In a public spec, most worrying are unexplained elements
- Best practice: choose constants from well-known math, like digits of $\pi$

## Dual_EC_DRBG (1)

- Pseudorandom generator in NIST standard, based on elliptic curve
- Looks like provable (slow enough!) but strangely no proof
- Specification includes long unexplained constants
- Academic researchers find:
  - Some EC parts look good
  - But outputs are statistically distinguishable

## Dual_EC_DRBG (2)

- Found 2007: special choice of constants allows prediction attacks
  - Big red flag for paranoid academics
- Significant adoption in products sold to US govt. FIPS-140 standards
  - Semi-plausible rationale from RSA (EMC)
- NSA scenario basically confirmed by Snowden leaks
  - NIST and RSA immediately recommend withdrawal