CSci 4271W
Development of Secure Software Systems
Day 20: 'S' protocols and crypto failures

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Outline

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

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.
```

Outline

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.
  - We'll return to this as a major example later

Outline

SSH

SSL/TLS

More causes of crypto failure

DNSSEC

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

Newer factoring problem (CCS'17)

- An Infineon RSA library used primes of the form $p = k \cdot M + (65537^a \bmod M)$
- Smaller problems: fingerprintable, less entropy
- Major problem: can factor with a variant of Coppersmith's algoritm
  - E.g., 3 CPU months for a 1024-bit key

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)
- FS&K: 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

Newer 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 π

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

Outline

SSH

SSL/TLS

More causes of crypto failure

DNSSEC

DNS: trusted but vulnerable

- Almost every higher-level service interacts with DNS
- UDP protocol with no authentication or crypto
  - Lots of attacks possible
- Problems known for a long time, but challenge to fix compatibly

DNSSEC goals and non-goals

+ Authenticity of positive replies
+ Authenticity of negative replies
+ Integrity
− Confidentiality
− Availability

First cut: signatures and certificates

- Each resource record gets an `RRSIG` signature
  - E.g., `A` record for one name→address mapping
  - Observe: signature often larger than data
- Signature validation keys in `DNSKEY` RRs
- Recursive chain up to the root (or other "anchor")

Add more indirection

- DNS needs to scale to very large flat domains like `.com`
- Facilitated by having single `DS` RR in parent indicating delegation
- Chain to root now includes `DS`es as well

Negative answers

- Also don't want attackers to spoof non-existence
  - Gratuitous denial of service, force fallback, etc.
- But don't want to sign "`x` does not exist" for all `x`
- Solution 1, `NSEC`: "there is no name between `acacia` and `baobab`"

Preventing zone enumeration

- Many domains would not like people enumerating all their entries
- DNS is public, but "not that public"
- Unfortunately `NSEC` makes this trivial
- Compromise: `NSEC3` uses password-like salt and repeated hash, allows opt-out

DANE: linking TLS to DNSSEC

- "DNS-based Authentication of Named Entities"
- DNS contains hash of TLS cert, don't need CAs
- How is DNSSEC's tree of certs better than TLS's?

Signing the root

- Political problem: many already distrust US-centered nature of DNS infrastructure
- Practical problem: must be very secure with no single point of failure
- Finally accomplished in 2010
  - Solution involves 'key ceremonies', international committees, smart cards, safe deposit boxes, etc.

Deployment

- Standard deployment problem: all cost and no benefit to being first mover
- Servers working on it, mostly top-down
- Clients: still less than 20%
- Will probably be common for a while: insecure connection to secure resolver

What about privacy?

- Users increasingly want privacy for their DNS queries as well
- Older DNSCurve and DNSCrypt protocols were not standardized
- More recent "DNS over TLS" and "DNS over HTTPS" are RFCs
- DNS over HTTPS in major browsers might have serious centralization effects