Secure Sockets Layer (SSL) / Transport Layer Security (TLS)

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What Problems Do SSL/TLS Solve?

- Two parties, client and server, *not previously known to one another*
  - i.e., haven’t been able to establish a shared secret in a secure room
- Want to **authenticate** one another
  - in today’s lecture, focus on client authenticating server; e.g., “am I talking to the real amazon.com server?”
- Want **secrecy** and **integrity** of communications in both directions
Problem: Man in the Middle Attacks

- Recall: public-key cryptography alone not enough to give robust authentication
  - Client can ask server to prove identity by signing data
  - But how does client know he has real server’s public key?

- Attacker may impersonate server
  - Gives client his own public key, claiming to be server
  - Client may send sensitive data to attacker
  - Attacker may send incorrect data back to client
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Man in the Middle Attacks (2)

- Attacker may not appear like server
  - e.g., might not have same content as real web server’s page
- Solution: attacker acts as **man in the middle**
  - Emulates server when talking to client
  - Emulates client when talking to server
  - Passes through most messages as-is
  - Substitutes own public key for client’s and server’s
  - Records secret data, or modifies data to cause damage
Challenge: Key Management

- Publish public keys in a well-known broadcast medium
  - e.g., in the telephone directory, or in the pages of the New York Times
  - How do you know you have the real phone directory, or New York Times?
  - How can software use these media?
- Exchange keys with people in person
- “Web of trust”: accept keys for others via friends you trust (used by PGP)
Approach to Key Management: Offline Certification Authorities (CAs)

- Idea: use digital signatures to indicate endorsement of binding between principal and public key
  - i.e., if I sign \{amazon.com, pubkey\}, I am stating, “I attest that amazon.com’s public key is pubkey.”

- Certification Authority (CA): third-party organization trusted by parties that wish to mutually authenticate

- Each CA has public/private key pair: \(K_{CA}, K_{CA}^{-1}\)
- CA creates certificate \(C_S\) for server S containing, e.g.,:
  - info = \{“www.amazon.com”, “Amazon, Inc.”, \(K_S\) = www.amazon.com’s public key, expiration date, CA’s name\}
  - sig = \(\{H(info)\}\)\( K_{CA}^{-1}\)

- Server S can present \(C_S\) to browser
- If browser knows \(K_{CA}\), can validate that CA attests that S’s public key is \(K_S\)
Approach to Key Management: Offline Certification Authorities (CAs)

- Idea: use digital signatures to indicate endorsement of binding between principal and public key

**Key benefit:** CA need not be reachable by C or S at time C wishes to authenticate S!

CAs and certificates are the heart of SSL’s authentication mechanism

- CA creates certificate $C_S$ for server S containing, e.g.,:
  - info = {“www.amazon.com”, “Amazon, Inc.”, $K_S = www.amazon.com$’s public key, expiration date, CA’s name}
  - sig = $\{H(info)\}^{K_{CA}}$

- Server S can present $C_S$ to browser
- If browser knows $K_{CA}$, can validate that CA attests that S’s public key is $K_S$
Offline Certification Authorities (2)

- Key benefit: CA need not be reachable by C or S at time C wishes to authenticate S!
  - Hence offline certification authority

- SSL/TLS model for browsers authenticating web servers:
  - Everybody trusts CA
  - Everybody knows CA’s public key (i.e., pre-configured into web browser)
SSL 3.0 Handshake Overview

Client

- **ClientHello**: client_version, client_random, client_cipher_list

Server

- **ServerHello**: server_version, server_random, server_cipher_list
- **ServerCertificate**: server_certificate_list
- **ClientKeyExchange**: \{pre_master_secret\}_K_S
- **ChangeCipherSpec**: client_cipher
- **Finished**: MAC<master_secret, all messages>
- **ChangeCipherSpec**: server_cipher
- **Finished**: MAC<master_secret, all messages>

compute session keys
Establishing Session Keys

- Client randomly generates pre-master secret, sends to server encrypted with server’s public key
- Server also contributes randomness in server_random
- Using both pre-master secret and server_random, server and client independently compute symmetric session keys:
  - Client MAC key
  - Server MAC key
  - Client Write key
  - Server Write key
  - Client IV
  - Server IV
Establishing Session Keys (2)

[SSL and TLS, Eric Rescorla]
Using Session Keys to Send Data

- Data encrypted by client and server using each’s own write key
- Data MAC’ed by client and server using each’s own MAC key
- Each SSL record (block) includes a sequence number for that sender, and a MAC over:
  - Sequence number
  - Data plaintext
  - Data length
Why MAC Data Length?

- Plaintext **padded to fit symmetric cipher block length**
- Length of data (without padding) must be sent to receiver
- SSL 2.0 didn’t MAC data length; only MAC’ed padded data itself
  - Active adversary could change plaintext data length field
  - MAC over data would still verify
  - **Attacker could truncate plaintext as desired!**
Why MAC Data Length?

- Plaintext padded to fit symmetric cipher

**Lesson:**
Always MAC “what you mean,” including all context used to interpret message at receiver

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Properties Provided by SSL (1)

• Secrecy: passive eavesdropper can’t decrypt data; pre-master secret encrypted with server’s public key, and server’s private key secret
• Authentication of server by client: can trust each data record came from server that holds private key matching public key in certificate
• Authentication of client by server? Not without client certificates...or client can send username/password over encrypted SSL channel
• Key exchange can’t be replayed; new random nonce from each side each time
Properties Provided by SSL (2)

• Data from earlier in session can’t be replayed
  – Caught by MAC

• Fake server can’t impersonate real one using real certificate and public key
  – Doesn’t know real server’s private key, so can’t decrypt pre-master secret from client

• Fake server obtains own certificate for own domain name from valid CA, supplies to client
  – If domain name differs from one in https:// URL, client detects mismatch when validating certificate
Forward Secrecy

• Suppose attacker records entire communication between client and server
• At later time, attacker obtains server’s private key
• If attacker cannot decrypt data from recorded session, scheme provides forward secrecy
• Does SSL 3.0 provide forward secrecy?
  – No.
Cipher Roll-Back

- SSL supports various ciphers of various key lengths and strengths
- Suppose attacker modifies cipher selection messages, to force client and server into using weak ciphers
- Each direction of handshake ends with MAC of all messages
- Can attacker adjust this MAC so it verifies?
  - No. Doesn’t know master_secret!
What Is CA Actually Certifying?

- That a public key belongs to someone authorized to represent a hostname?
- That a public key belongs to someone who is associated in some way with a hostname?
- That a public key belongs to someone who has many paper trails associated with a company related to a hostname?
- That the CA has no liability?
- >100-page Certification Practice Statement (CPS)!

(CPS)!
How to Get a VeriSign Certificate

• Pay VeriSign ($300)
• Get DBA license from city hall ($20)
  – No on-line check for name conflicts; can I do business as Microsoft?
• Letterhead from company (free)
• Notarize document (need driver’s license) (free)
• Easy to get fraudulent certificate
  – Maybe hard to avoid being prosecuted afterwards...
• But this is just VeriSign’s policy
  – many other CAs...
CA Security

• How trustworthy is a VeriSign certificate?

In mid-March 2001, VeriSign, Inc., advised Microsoft that on January 29 and 30, 2001, it issued two . . . [fraudulent] certificates. ... The common name assigned to both certificates is “Microsoft Corporation.”

VeriSign has revoked the certificates. . . .
However. . . it is not possible for any browser’s CRL-checking mechanism to locate and use the VeriSign CRL.

– Microsoft Security Bulletin MS01-017
CA Security (2)

• In 2011, it was reported that DigiNotar, a Dutch CA, had its servers compromised
  – Believed DigiNotar unaware of compromise for weeks

• Intruders generated over 500 forged SSL certificates, including for google.com

• Between 27 July 2011 and 29 August 2011, over 300K IP addresses accessed web sites presenting this forged SSL certificate for google.com
  – 99% of IP addresses in Iran
  – Assumption by press: forged certificate used to monitor Iranian Gmail users’ email
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Lesson:
The weakest CA your browser trusts by default may be very weak indeed