DROWN - Breaking TLS using SSLv2

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A history of obsolete crypto

• SSLv2 published in 1995, immediately broken
  – Devastating MitM attacks
  – Common wisdom: SSLv2 is better than plaintext

• Before DROWN: OK to keep SSLv2 enabled, esp. for email.
Our results: SSLv2 breaks TLS
DROWN - Overview

- Attacker decrypts intercepted TLS traffic
- Cross-protocol attack
  - Attack TLS server using SSLv2 server
  - Attack HTTPS server using email server - SSLv2 much more prevalent on email ports
- 22% of trusted HTTPS hosts vulnerable with cross-protocol use
TLS RSA Handshake

Client
- Generate ClientRandom
- Generate PMS

Server
- Generate ServerRandom

ClientRandom → ServerRandom, PK

Enc(PK, PMS), Client Finished → Server Finished
PKCS #1 v1.5

- Textbook RSA: \( k^e \mod N \)
  - Problem: No randomization
- In real-life:
  - PKCS #1 v1.5: pad \( k \) to length of \( N \) with random padding

![Diagram of PKCS #1 v1.5 padding](image)
Bleichenbacher’s Attack

• If padding is incorrect after decryption, then…
  – Send an error message
  – Attacker can deduce if padding was correct.

• Conclusion: The server has to behave as if the padding was valid!
Bleichenbacher’s Attack

- If padding is incorrect after decryption, then...
  The server has to behave as if the padding was valid!
- Solution: Server generates a random “replacement” plaintext, continues as usual.
Differences between SSLv2 and TLS

- Server authenticates **first** (sends first message encrypted with symmetric key)
- Short secrets for export grade crypto:
  - SSLv2: 40 bit key.
  - TLS: 48 byte (384 bit) key.
An important observation

- Attacker connects twice with **same** RSA ciphertext.
- Ciphertext **valid**:
- 2 server replies encrypted with **same** key.
An important observation

- Attacker connects twice with same RSA ciphertext.
- Ciphertext not valid:
- 2 server replies encrypted with different keys.
The SSLv2 RSA Decryption Oracle

- Attacker breaks 40 bit key for both messages.
- Ciphertext valid:
  - Both keys will be the unpadded RSA plaintext -> keys will be identical.
The SSLv2 RSA Decryption Oracle

- Attacker breaks 40 bit key for both messages.
- If ciphertext is invalid:
  - Both keys will be randomly generated -> keys will be different.
- Reminder: If attacker can distinguish between valid/invalid RSA message, attacker can decrypt TLS!
DROWN: Attack Outline

- Attacker records ~1,000 modern TLS connections.
- Attacker morphs TLS RSA ciphertext to SSLv2 ciphertext – Uses SSLv2 Bleichenbacher oracle to decrypt.
- Client never makes an SSLv2 connection.
Offline work

• Attacker executes ~10K queries, breaks 40-bit key for each Bleichenbacher query.
  – $2^{50}$ keys tested overall.
• Feasible on modern hardware:
  – Naive CPU implementation: $21K$ of CPU, 114 days.
• Highly optimized GPU implementation:
  – $18K$ of GPUs, 18 hours, or $440$ on AWS, 8 hours.
• Special DROWN: Implementation vulnerability in OpenSSL
  – 22% of trusted HTTPS servers are vulnerable
  – Negligible computation, see paper
Key reuse

- Attack HTTPS server using email server
- Widespread key reuse:
  - No protocol version in certificates
  - Certificates cost money (EV)
# Impact of Key Reuse

<table>
<thead>
<tr>
<th>Protocol</th>
<th>Port</th>
<th>All Certificates</th>
<th>Trusted Certificates</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>TLS</td>
<td>SSLv2</td>
</tr>
<tr>
<td><strong>SMTP</strong></td>
<td>25</td>
<td>3,357 K</td>
<td>936 K (28%)</td>
</tr>
<tr>
<td><strong>POP3</strong></td>
<td>110</td>
<td>4,193 K</td>
<td>404 K (10%)</td>
</tr>
<tr>
<td><strong>IMAP</strong></td>
<td>143</td>
<td>4,202 K</td>
<td>473 K (11%)</td>
</tr>
<tr>
<td><strong>HTTPS</strong></td>
<td>443</td>
<td>34,727 K</td>
<td>5,975 K (17%)</td>
</tr>
<tr>
<td><strong>SMTPS</strong></td>
<td>465</td>
<td>3,596 K</td>
<td>291 K (8%)</td>
</tr>
<tr>
<td><strong>SMTP</strong></td>
<td>587</td>
<td>3,507 K</td>
<td>423 K (12%)</td>
</tr>
<tr>
<td><strong>IMAPS</strong></td>
<td>993</td>
<td>4,315 K</td>
<td>853 K (20%)</td>
</tr>
<tr>
<td><strong>POP3S</strong></td>
<td>995</td>
<td>4,322 K</td>
<td>884 K (20%)</td>
</tr>
</tbody>
</table>
Takeaways

• Export crypto weakens modern protocols
  – Export RSA (FREAK), DH (Logjam), symmetric crypto (DROWN)
  – More weakened crypto seems ill-advised.

• Should remove obsolete crypto.
  – Long history of attacks: POODLE, Fake CA, RC4, FREAK, Logjam, Lucky 13, Sloth, ...
  – Is DROWN the last?
    • Mac-then-Encrypt, SHA-1, ...?
Thank you!
drownattack.com

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Special DROWN

- Implementation vulnerability in OpenSSL
  - because of added complexity from export ciphers.
- Present in 22% of trusted HTTPS.
- No symmetric key brute-forcing, negligible computation. Runs in a minute on a laptop.
- Allows MitM attack against DH TLS:
  - “Downgrade” the key exchange to RSA, use special DROWN to decrypt RSA ciphertext online.
QUIC

• Experimental TLS-like protocol by Google.
• 0-RTT
• Server signs a static config block, containing DH parameters, supported ciphersuites etc.
• If the client knows nothing, it prompts for the config block.
• Otherwise, it calculates shared keys and starts talking.
• Server indicates QUIC support, client will henceforth connect with QUIC
  – Can indicate support over plaintext.
QUIC MitM Attack

• Static signatures -> Forge a signature once, use it forever.
• Discovery over plaintext -> Server doesn’t even support QUIC, attacker fakes support over plaintext.
• Google plans to fix both these issues.
• Attack cost with general DROWN: ~$10M.
• Attack cost with special DROWN: $2^{25}$ SSLv2 connections, no large computation.