DROWN - Breaking TLS using SSLv2

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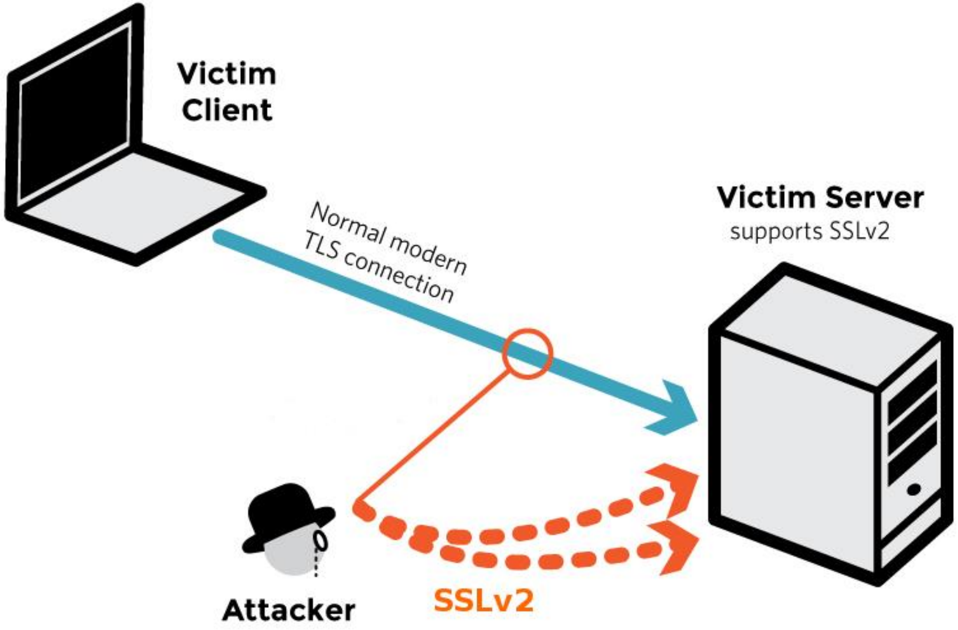
A history of obsolete crypto

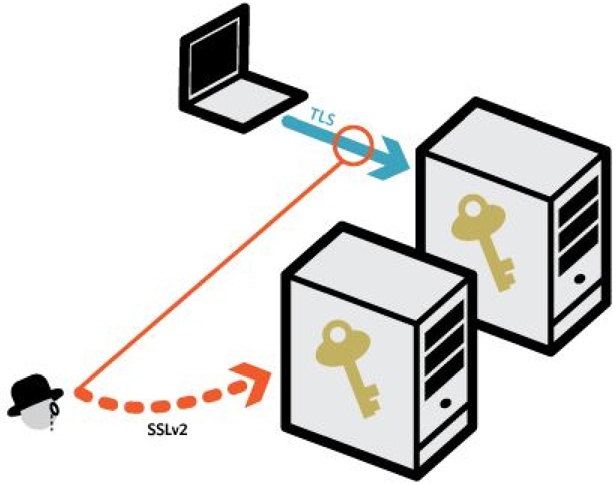
- SSLv2 published in 1995, immediately broken
  - Devastating MitM attacks
  - Common wisdom: SSLv2 is better than plaintext
- Before DROWN: OK to keep SSLv2 enabled, esp. for email.

Our results: SSLv2 breaks TLS

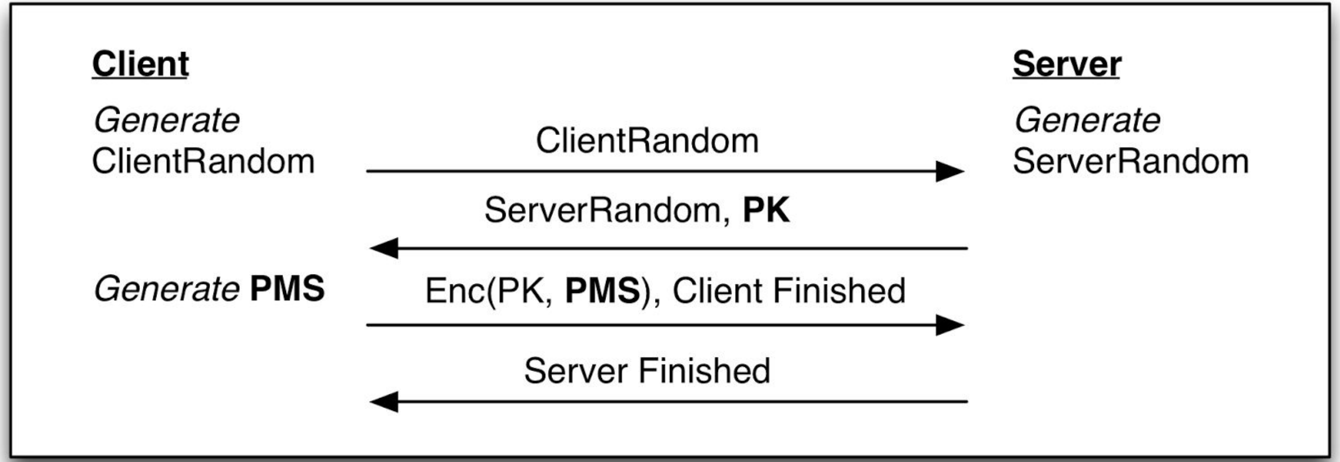


DROWN - Overview

- 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

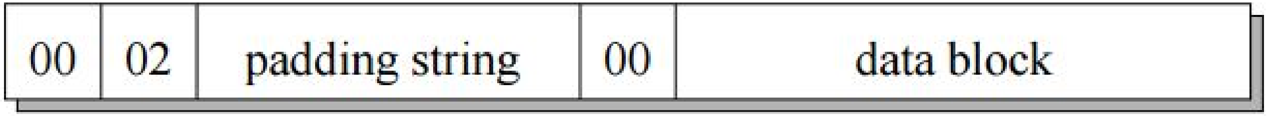


TLS RSA Handshake



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

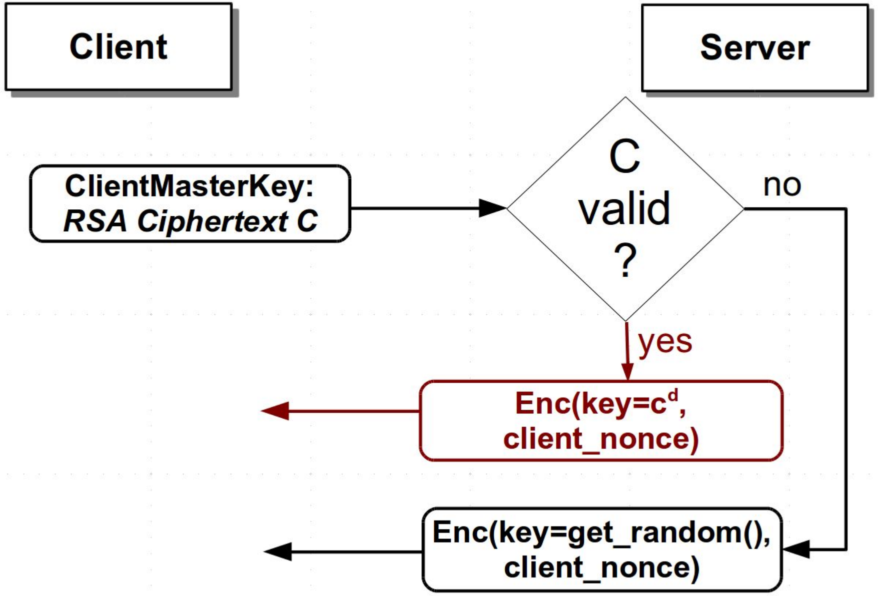


Bleichenbacher's Attack

- 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!**

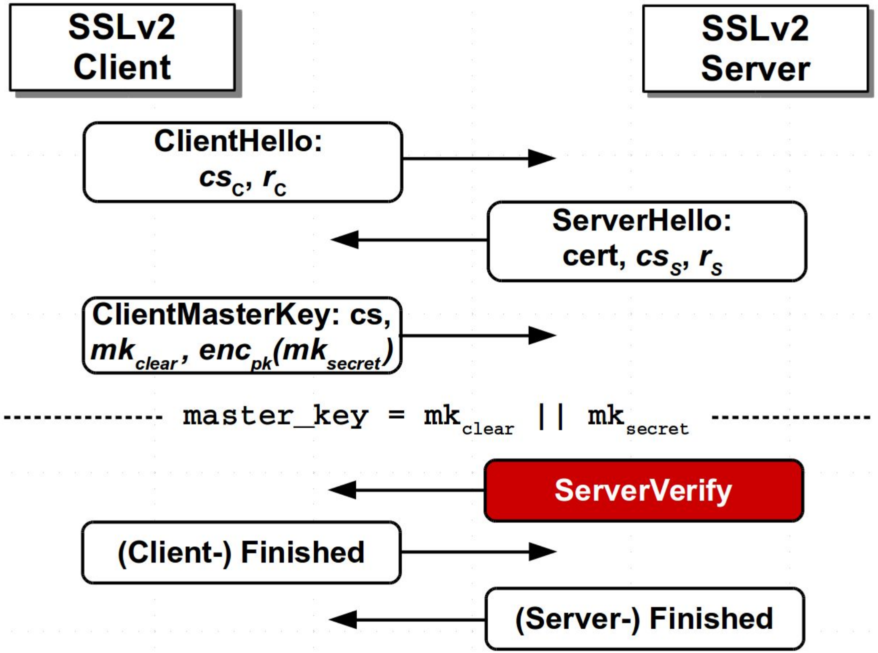
Bleichenbacher's Attack

- 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.



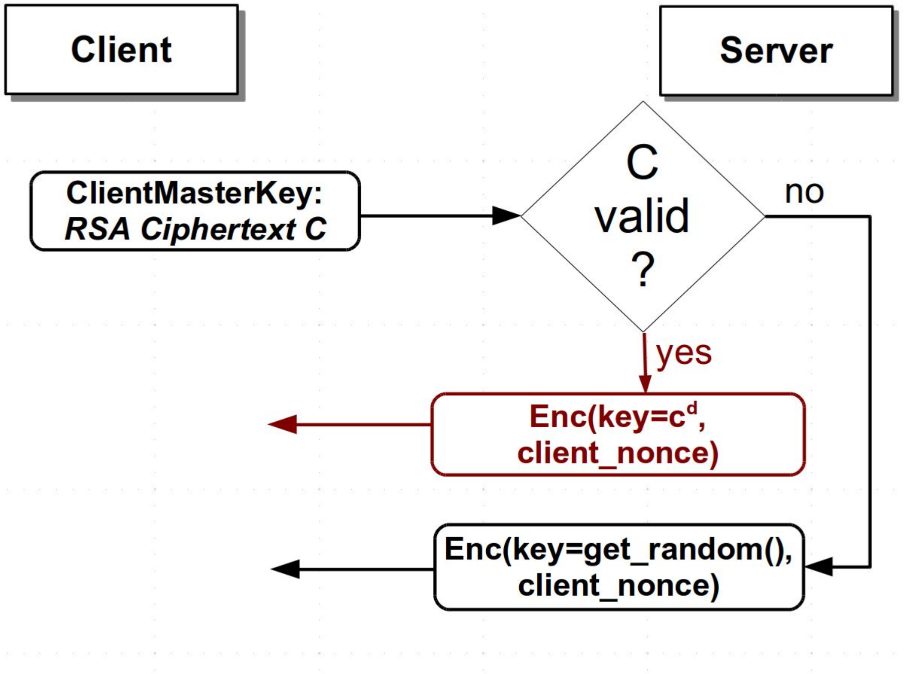
Differences between SSLv2 and TLS

- 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.



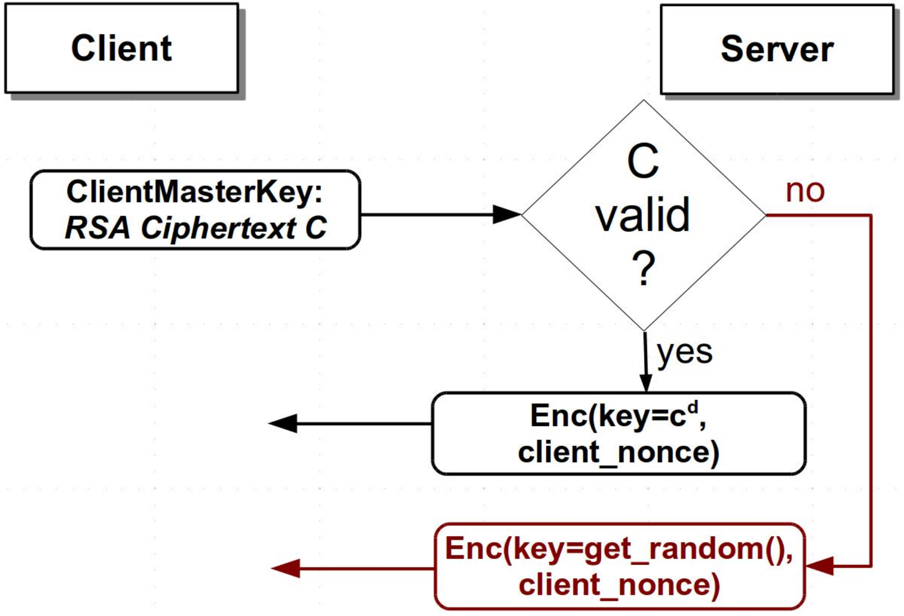
An important observation

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



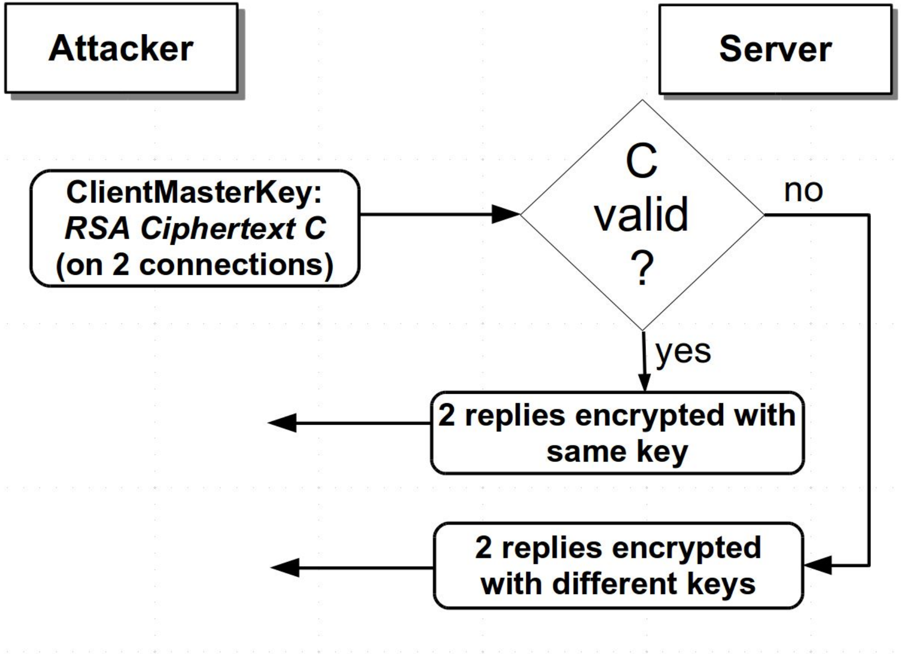
An important observation

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



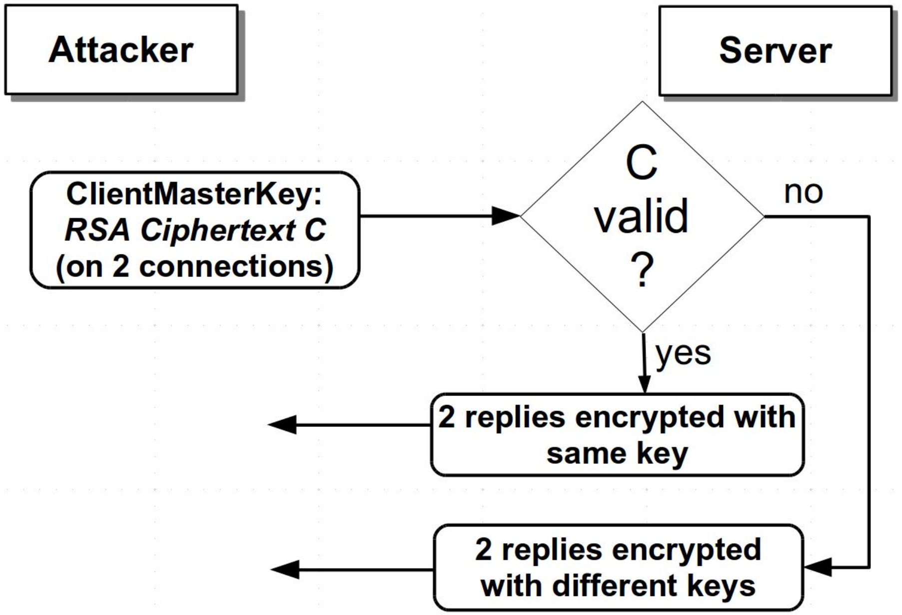
The SSLv2 RSA Decryption Oracle

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



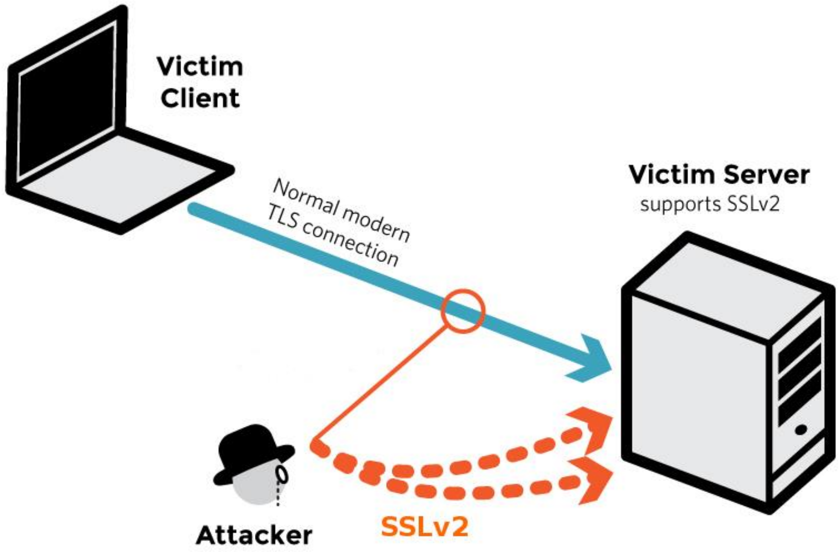
The SSLv2 RSA Decryption Oracle

- 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.

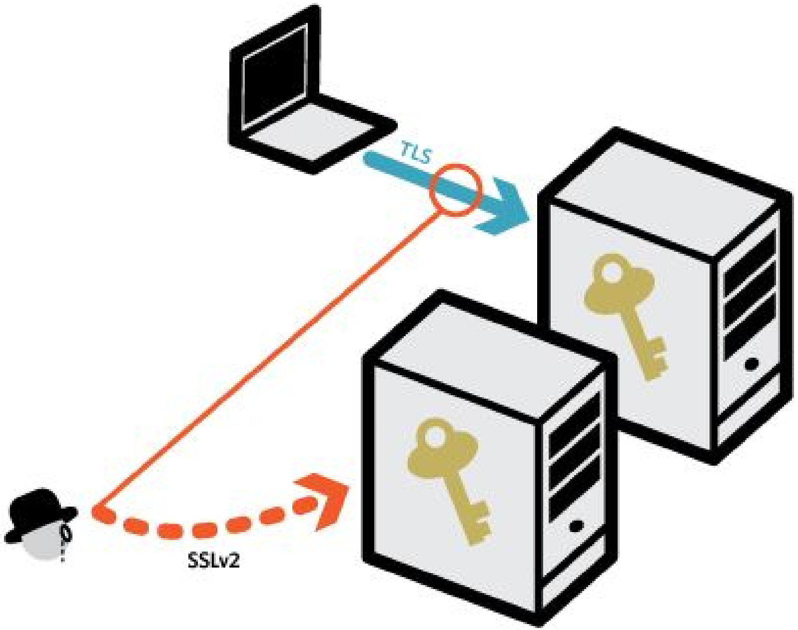


Offline work

- 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

Protocol	Port	All Certificates			Trusted Certificates		
		TLS	SSLv2	Vulnerable Key	TLS	SSLv2	Vulnerable Key
SMTP	25	3,357 K	936 K (28%)	1,666 K (50%)	1,083 K	190 K (18%)	686 K (63%)
POP3	110	4,193 K	404 K (10%)	1,764 K (42%)	1,787 K	230 K (13%)	1,031 K (58%)
IMAP	143	4,202 K	473 K (11%)	1,759 K (59%)	1,781 K	223 K (13%)	1,022 K (58%)
HTTPS	443	34,727 K	5,975 K (17%)	**11,444 K (33%)**	17,490 K	1,749 K (10%)	**3,931 K (22%)**
SMTPS	465	3,596 K	291 K (8%)	1,439 K (40%)	1,641 K	40 K (2%)	949 K (58%)
SMTP	587	3,507 K	423 K (12%)	1,464 K (40%)	1,657 K	133 K (8%)	986 K (59%)
IMAPS	993	4,315 K	853 K (20%)	1,835 K (43%)	1,909 K	260 K (14%)	1,119 K (59%)
POP3S	995	4,322 K	884 K (20%)	1,919 K (44%)	1,974 K	304 K (15%)	1,191 K (60%)

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.