ROBOT

Return of Bleichenbacher's Oracle Threat

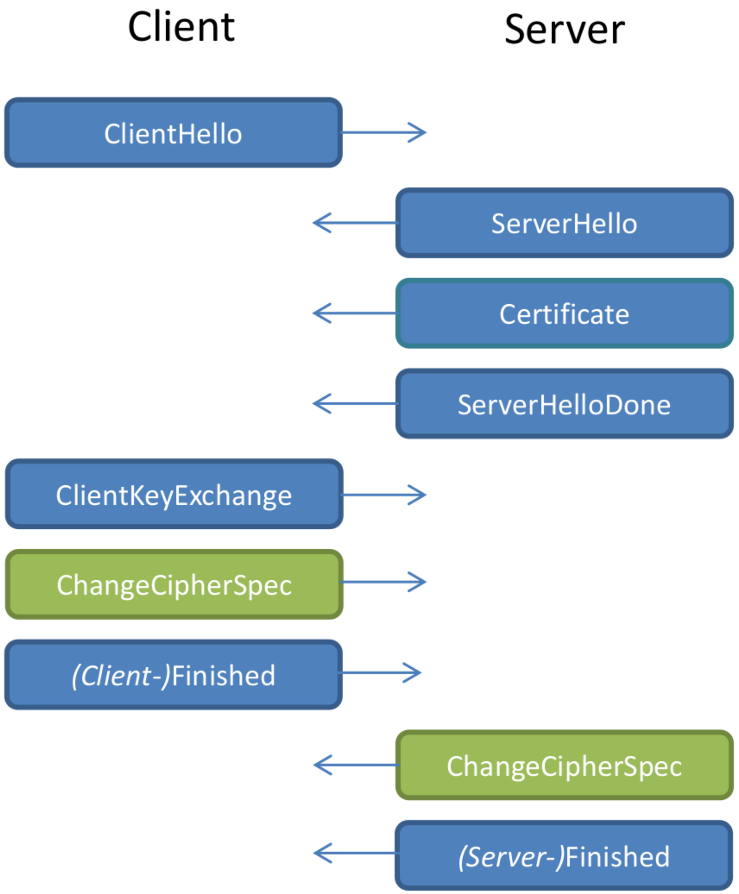
Let's look at the TLS handshake

Client and Server want to get a Shared Secret

Two ways

- RSA Encryption
- Diffie Hellman (DHE or ECDHE) with Signatures (usually RSA), provides forward secrecy

Let's look at RSA Encryption



Client

Server

ClientHello

ServerHello

Certificate

ServerHelloDone

ClientKeyExchange

ChangeCipherSpec

*(Client-)*Finished

ChangeCipherSpec

*(Server-)*Finished

ClientKeyExchange

RSA-Encrypted Pre-Master Secret (random data)

Naive RSA encryption

Message M · public key e, N · private key d

```
Encrypt: E = M^e mod N
Decrypt: M = E^d mod N
```

This naive variant is called Textbook RSA and totally insecure.

Why?

Encrypting the messages "0" and "1":

$$E = 0^{d} \bmod N = 0$$

$$E = 1^{d} \bmod N = 1$$

Padding

PKCS #1 1.5

Padding in TLS RSA Encryption

```
00 | 02 | [random] | 00 | 03 | 03 | [secret]
```

```
00 | 02 | [random] | 00 | 03 | 03 | [secret]
^^^^^^^
```

Block type (encryption)

```
00 | 02 | [random] | 00 | 03 | 03 | [secret]
          ^^^^^^^^
```

Random bytes without zeros

```
00 | 02 | [random] | 00 | 03 | 03 | [secret]
                     ^^
```

End of padding

```
00 | 02 | [random] | 00 | 03 | 03 | [secret]
                          ^^^^^^^
```

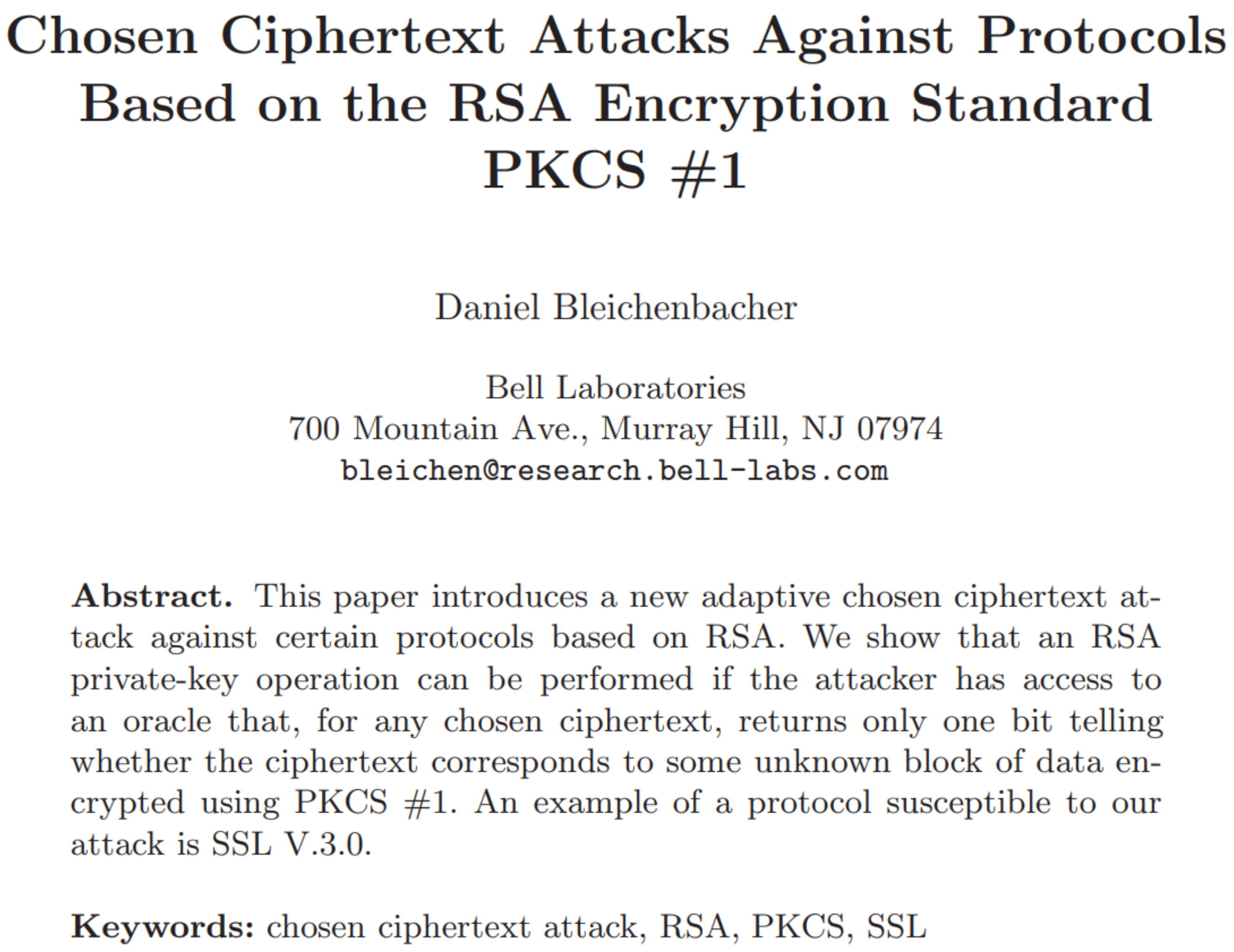
TLS Version from ClientHello

03 03 stands for TLS 1.2

(Don't ask, other story...)

```
00 | 02 | [random] | 00 | 03 | 03 | [secret]
                                    ^^^^^^^^
```

Random bytes



Chosen Ciphertext Attacks Against Protocols Based on the RSA Encryption Standard PKCS #1

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Abstract. This paper introduces a new adaptive chosen ciphertext attack against certain protocols based on RSA. We show that an RSA private-key operation can be performed if the attacker has access to an oracle that, for any chosen ciphertext, returns only one bit telling whether the ciphertext corresponds to some unknown block of data encrypted using PKCS #1. An example of a protocol susceptible to our attack is SSL V.3.0.

Keywords: chosen ciphertext attack, RSA, PKCS, SSL

Bleichenbacher 1998

Decrypted RSA block must always start with 00 02.
What should the server do if it doesn't?

Idea: Just reject the message with an error.
(e. g. "wrong block type prefix")

We just gave an attacker some information about encrypted data.

Correct prefix:

```
00 02 00 [...] 00 <= M < 00 03 00 [...] 00
```

Bad prefix:

```
M < 00 02 00 [...] 00 or M >= 00 03 00 [...] 00
```

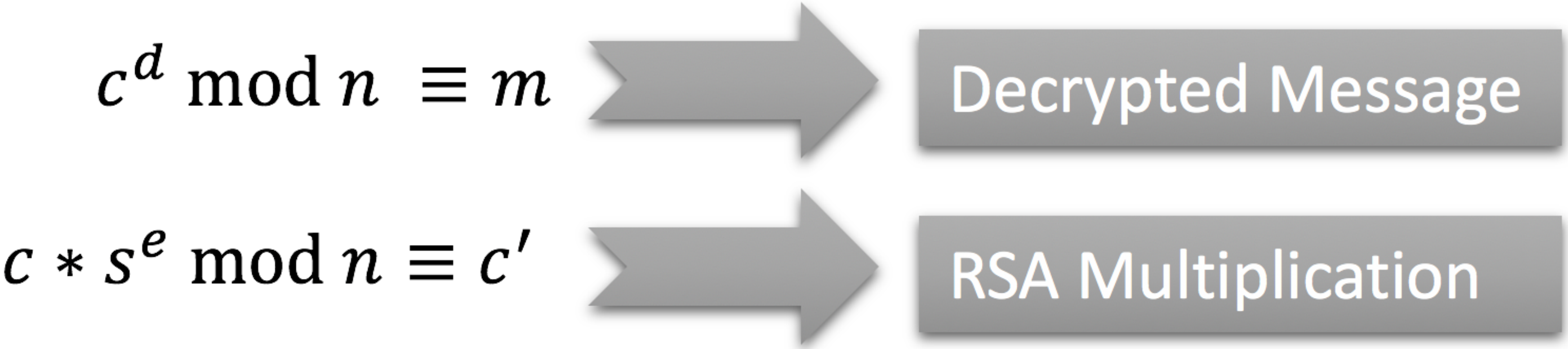
RSA Malleability

$2^{e} * RSA_{Enc}(M) = RSA_{Enc}(2*M)$

$3^{e} * RSA_{Enc}(M) = RSA_{Enc}(3*M)$

$n^{e} * RSA_{Enc}(M) = RSA_{Enc}(n*M)$

RSA operates on numbers



$c^d \bmod n \equiv m$

Decrypted Message

$c * s^e \bmod n \equiv c'$

RSA Multiplication

Valid padding implies *m*s* starts with 0x0002

So what?

Let's consider a basic example...

If 3000*x* is a 5-digit decimal starting ‘45’, then:

$$45000 \leq 3000x < 46000$$

$$15 \leq x < 15.33$$

If 3010*x* is also 5-digit decimal starting ‘45’, then:

$$45000 \leq 3010x < 46000$$

$$14.95 \leq x < 15.28$$

This combines into a smaller range:

$$15 \leq x < 15.28$$

Each "conforming" value narrows the range

This works for RSA too...

...but it's a little more complicated

$$[0x0002\ \ldots] \leq (\mathrm{m} \cdot s) \bmod N < [0x0003\ \ldots]$$

Or

$$\frac{[0x0002\ \ldots] + rN}{s} \leq m < \frac{[0x0003\ \ldots] + rN}{s}$$

TL;DR is that each positive response from the oracle narrows in on the decrypted value

After enough oracle queries, the range is small enough to brute force search

Variations

```
00 | 02 | [random] | 00 | 03 | 03 | [secret]
```

Depending on the checks done by the server (block prefix, padding length, TLS version) we get different oracles.

The "strength" of an oracle depends on which checks are revealed by the server.

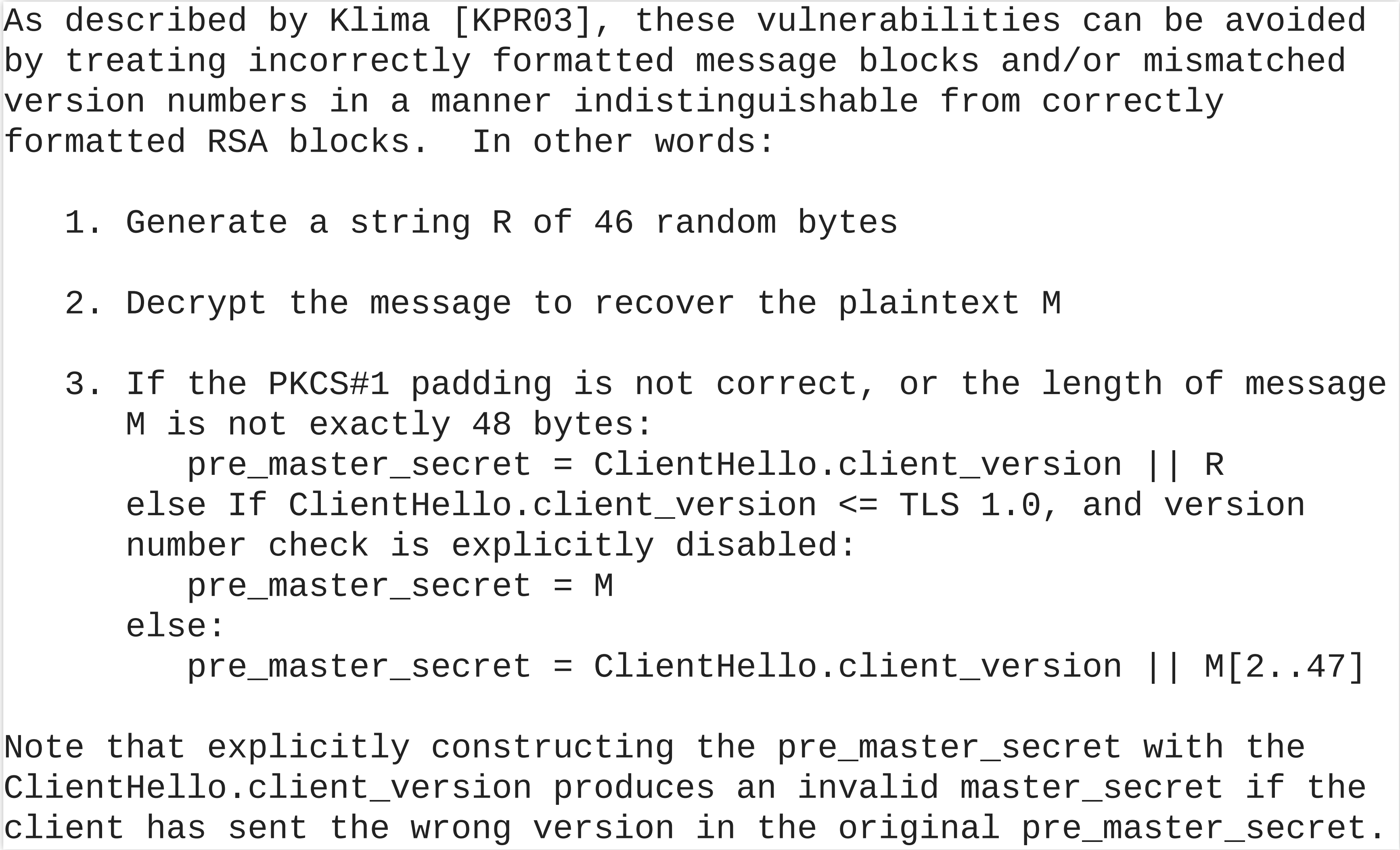
How to fix?

Server must not give the client any information about the decrypted data.

```
The best way to avoid vulnerability to this attack is to treat
incorrectly formatted messages in a manner indistinguishable from
correctly formatted RSA blocks. Thus, when it receives an
incorrectly formatted RSA block, a server should generate a
random 48-byte value and proceed using it as the premaster
secret. Thus, the server will act identically whether the
received RSA block is correctly encoded or not.
```

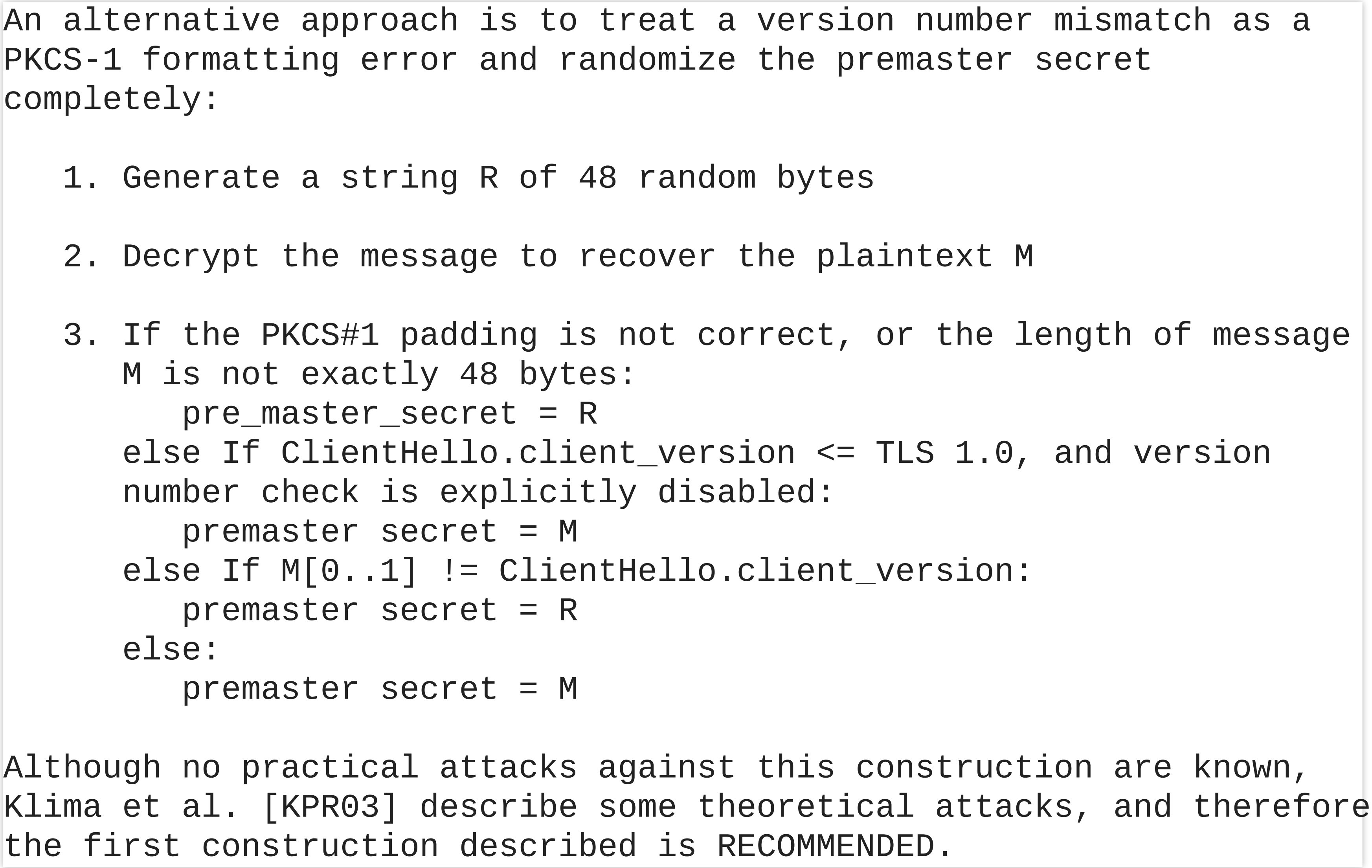
TLS 1.0 / RFC 2246, 1999

In case of a bad padding a server should pretend everything is alright and replace the decrypted data with a random value.



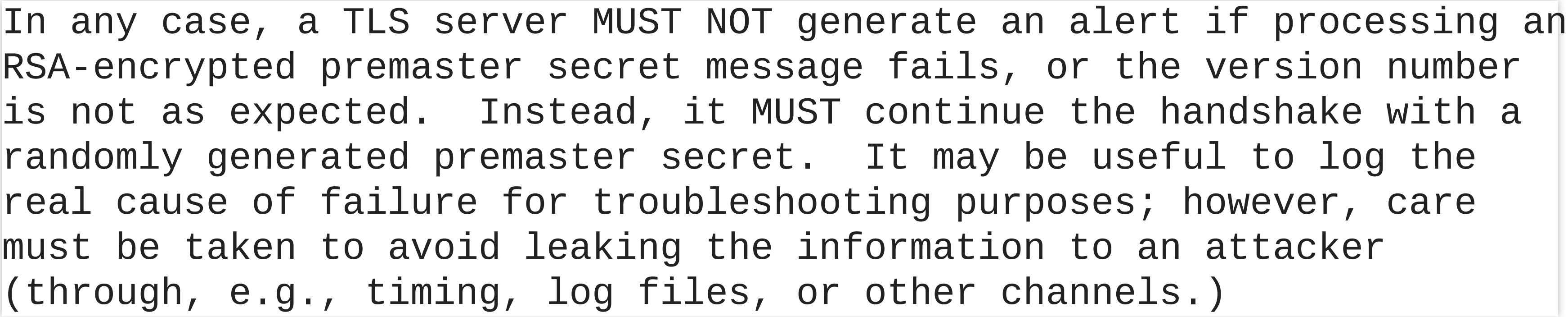
```
As described by Klima [KPR03], these vulnerabilities can be avoided
by treating incorrectly formatted message blocks and/or mismatched
version numbers in a manner indistinguishable from correctly
formatted RSA blocks.  In other words:

   1. Generate a string R of 46 random bytes

   2. Decrypt the message to recover the plaintext M

   3. If the PKCS#1 padding is not correct, or the length of message
      M is not exactly 48 bytes:
         pre_master_secret = ClientHello.client_version || R
      else If ClientHello.client_version <= TLS 1.0, and version
      number check is explicitly disabled:
         pre_master_secret = M
      else:
         pre_master_secret = ClientHello.client_version || M[2..47]

Note that explicitly constructing the pre_master_secret with the
ClientHello.client_version produces an invalid master_secret if the
client has sent the wrong version in the original pre_master_secret.
```

TLS 1.2 / RFC 5246, 2008



```
An alternative approach is to treat a version number mismatch as a
PKCS-1 formatting error and randomize the premaster secret
completely:

   1. Generate a string R of 48 random bytes

   2. Decrypt the message to recover the plaintext M

   3. If the PKCS#1 padding is not correct, or the length of message
      M is not exactly 48 bytes:
         pre_master_secret = R
      else If ClientHello.client_version <= TLS 1.0, and version
      number check is explicitly disabled:
         premaster secret = M
      else If M[0..1] != ClientHello.client_version:
         premaster secret = R
      else:
         premaster secret = M

Although no practical attacks against this construction are known,
Klima et al. [KPR03] describe some theoretical attacks, and therefore
the first construction described is RECOMMENDED.
```

TLS 1.2 / RFC 5246, 2008



In any case, a TLS server MUST NOT generate an alert if processing an RSA-encrypted premaster secret message fails, or the version number is not as expected. Instead, it MUST continue the handshake with a randomly generated premaster secret. It may be useful to log the real cause of failure for troubleshooting purposes; however, care must be taken to avoid leaking the information to an attacker (through, e.g., timing, log files, or other channels.)

TLS 1.2 / RFC 5246, 2008

A server generates a random value before parsing the message, just in case.

If the message has a bad padding then the server is supposed to replace it with the random value.

If the message has a bad version then the server can choose whether to replace it with a random value or to fix the version.

The second variant is better, but we like to make the standard longer, therefore we describe both and let the implementor choose.

By the way: Everything must be timing-safe. Please figure out how to do that.

Totally easy!

Of course everyone will get this right.

This attack has been known since 1998 and is well documented, so everyone has a regression test for it, right?

Maybe not...

Let's test

Send different broken RSA-encrypted ClientKeyExchange packages.

If replies differ we have an oracle.

TLS alerts, Duplicate TLS alerts, TCP connection resets, Timeouts

First hit: facebook.com

We have to attack Facebook!

Goal: We would like to sign a message with the private key from facebook.com.

This attack needs tens of thousands of connections, so we want to be fast.

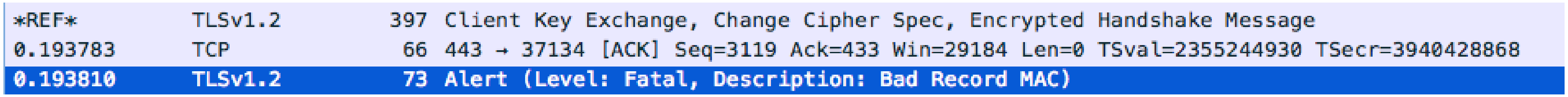
We tried all AWS locations, on some we got ping times to facebook around 2-3 ms.

Eventually we figured out that our attack ran much faster with TCP_NODELAY set.

After several tries we did it! We successfully signed a message with Facebook's private key.

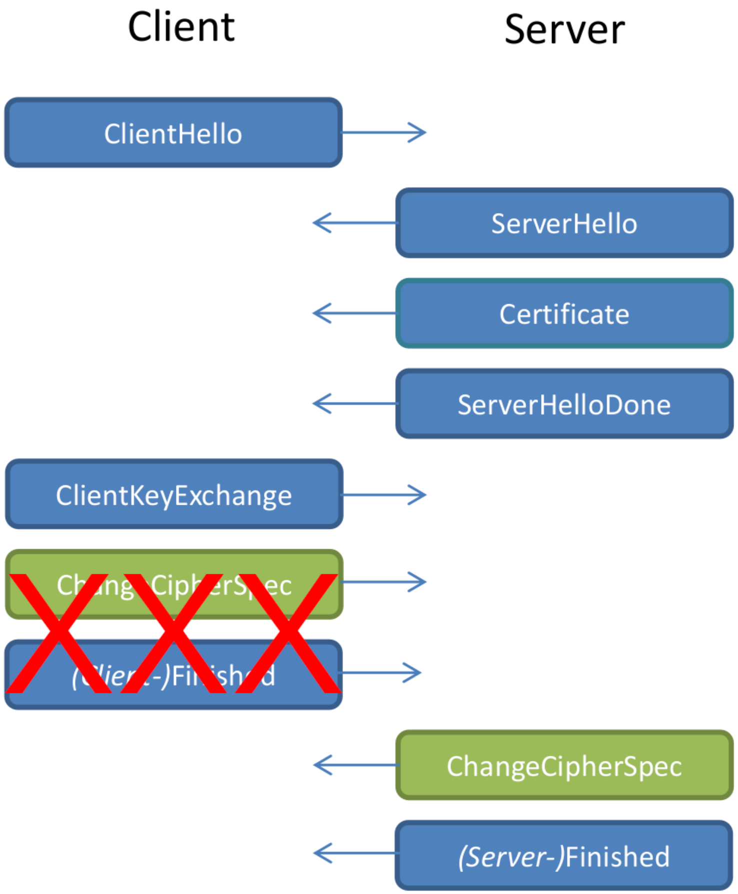
We reported it to Facebook. They fixed it.

Facebook.com now sends a generic TLS alert...



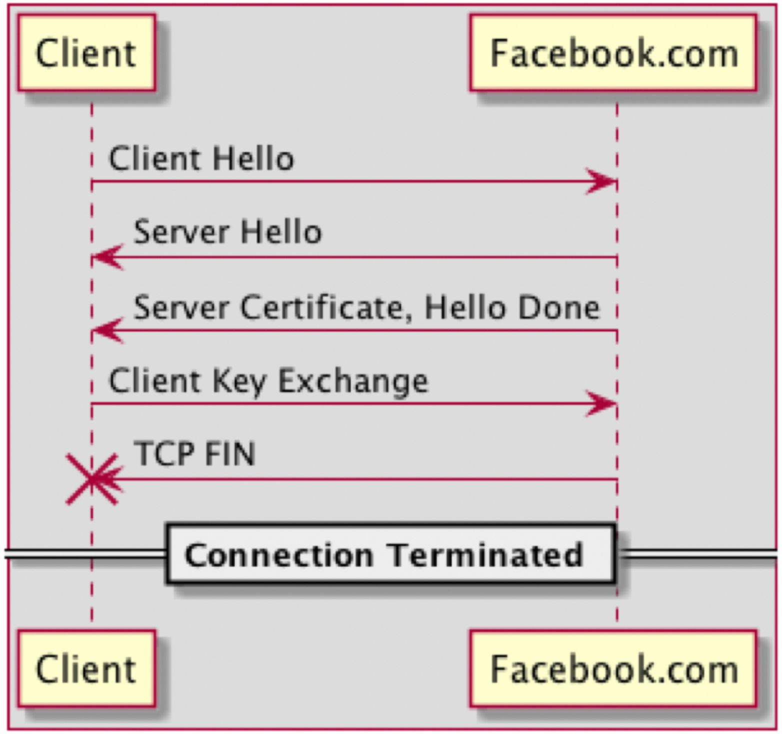
```
*REF*         TLSv1.2        397  Client Key Exchange, Change Cipher Spec, Encrypted Handshake Message
0.193783      TCP             66  443 → 37134 [ACK] Seq=3119 Ack=433 Win=29184 Len=0 TSval=2355244930 TSecr=3940428868
0.193810      TLSv1.2         73  Alert (Level: Fatal, Description: Bad Record MAC)
```

But what happens if we alter the message flow?

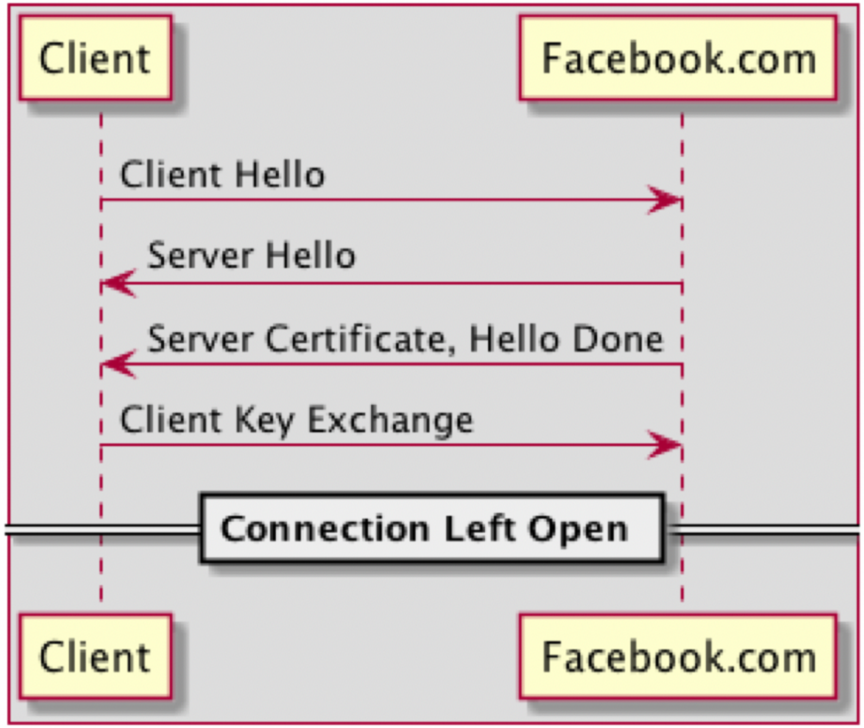

Client
Server
ClientHello
ServerHello
Certificate
ServerHelloDone
ClientKeyExchange
ChangeCipherSpec
(Client-)Finished
ChangeCipherSpec
(Server-)Finished

Facebook's Shortflow Oracle

Invalid Padding



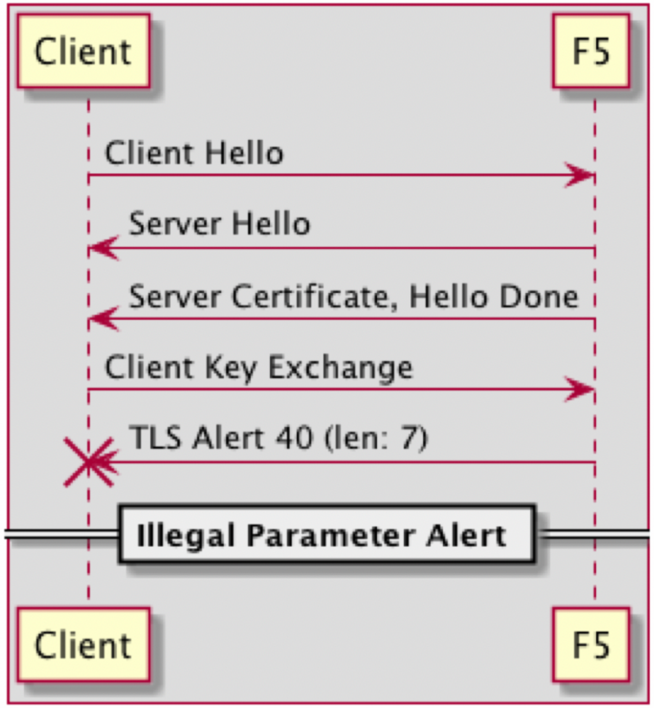
PKCS Conforming



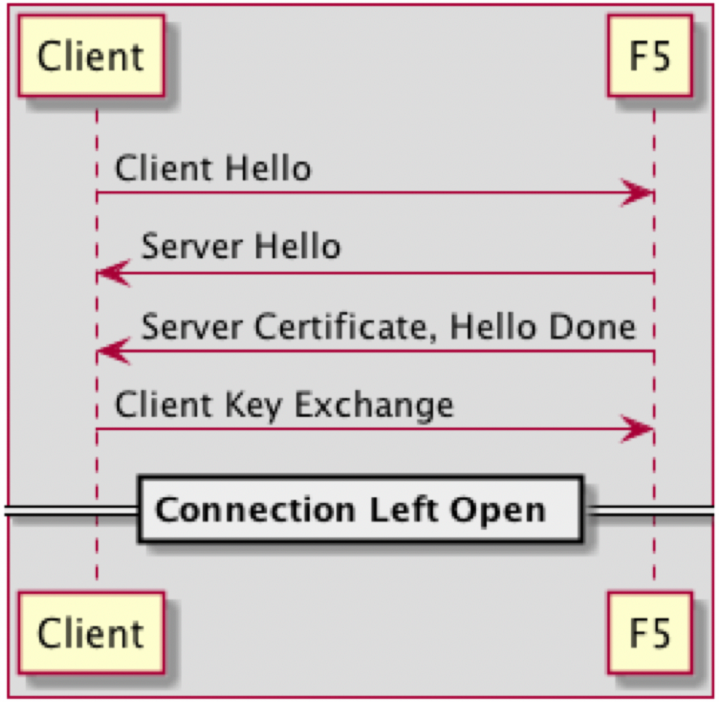
And Facebook was not alone...

F5 BigIP Oracle

Invalid Padding

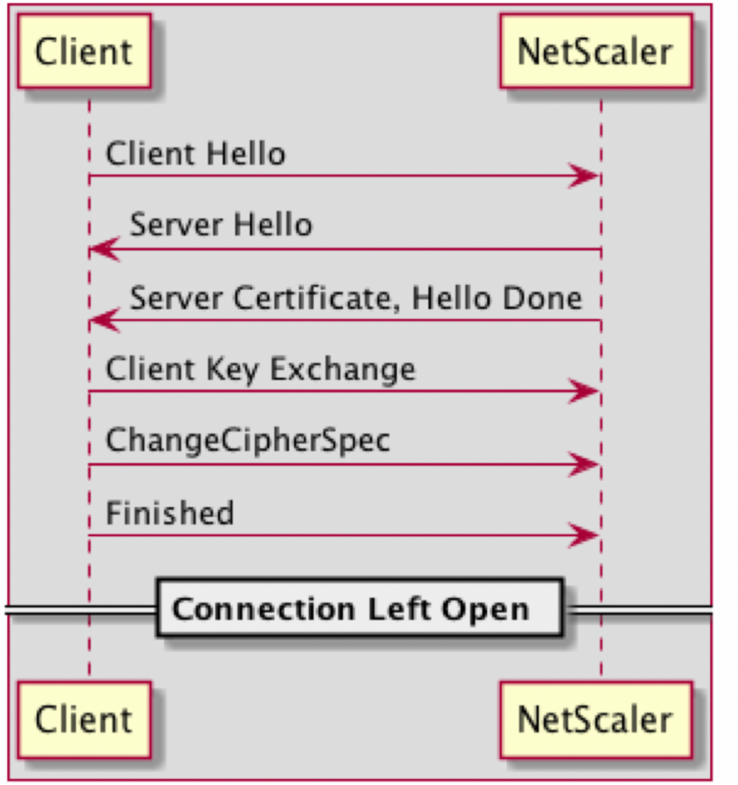


PKCS Conforming



Citrix NetScaler Oracle

Invalid Padding



Client

NetScaler

Client Hello

Server Hello

Server Certificate, Hello Done

Client Key Exchange

ChangeCipherSpec

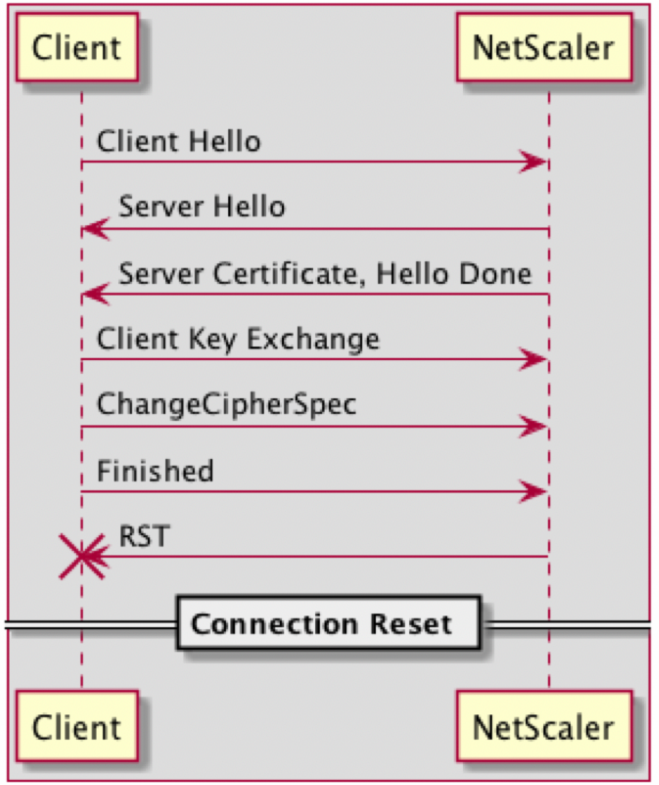
Finished

Connection Left Open

Client

NetScaler

PKCS Conforming



Client

NetScaler

Client Hello

Server Hello

Server Certificate, Hello Done

Client Key Exchange

ChangeCipherSpec

Finished

RST

Connection Reset

Client

NetScaler

Impact

If server or client only supports TLS_RSA modes then one can use Bleichenbacher attacks to directly decrypt traffic.

However RSA encryption modes aren't very popular any more, so this is often not the case.

If server and client support forward secrecy modes Man in the Middle attack may be possible, but requires performing attack very fast.

We have not tried this practically.

facebook.com wasn't the only vulnerable host

apple.com

cisco.com

ebay.com

paypal.com

accountservices.microsoft.com

Tracking down vendors is hard

Vendors / Products

F5, Citrix, Radware, Cisco ACE and ASA, Bouncy Castle, Erlang, WolfSSL, Palo Alto Networks, IBM, Symantec, Unisys, Cavium

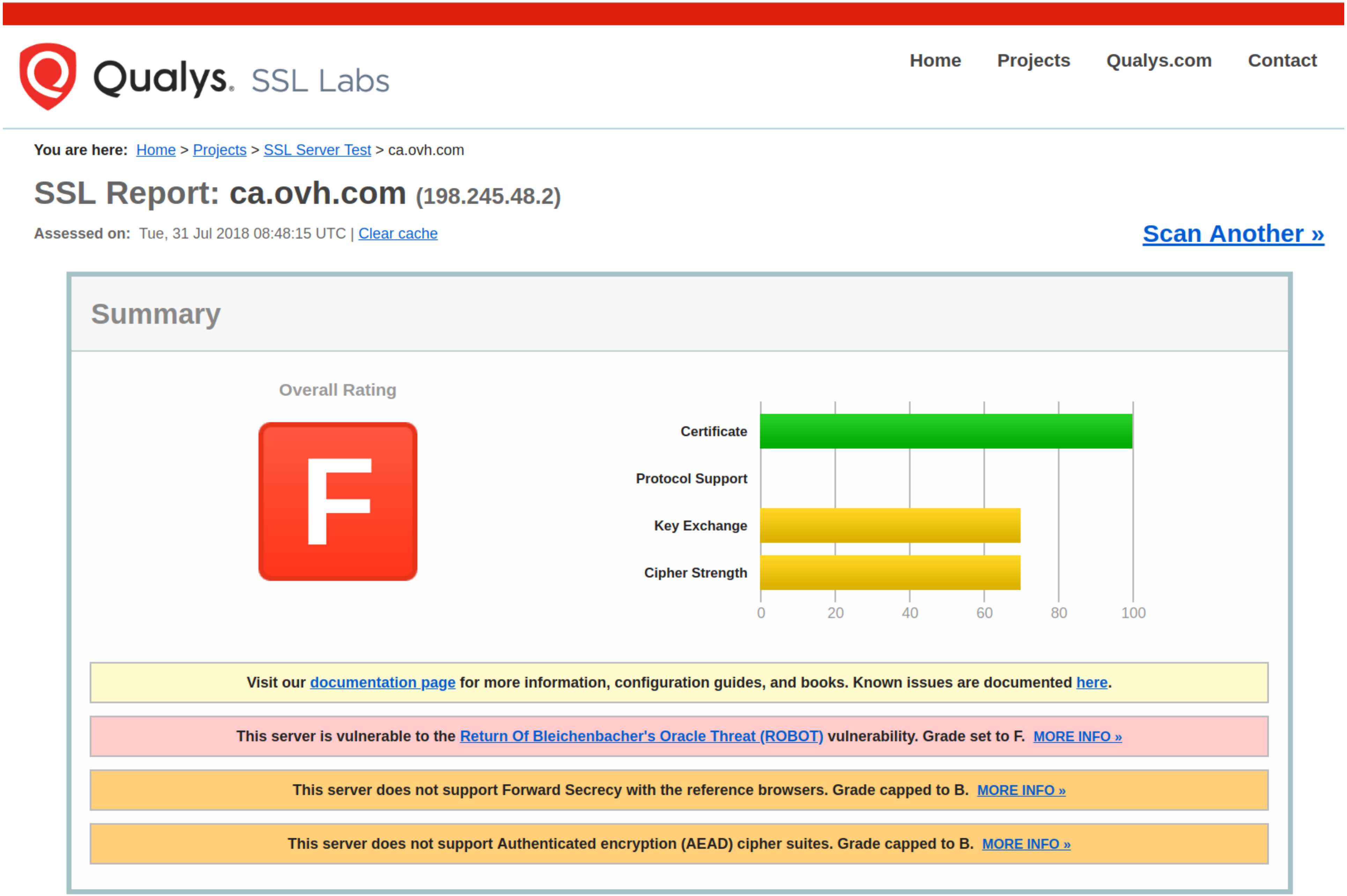
Cisco ACE

Vulnerability is particularly severe, because these devices support no other cipher modes.

Cisco: We won't fix it, it's out of support for several years.

But there were plenty of webpages still running with these devices.

Like cisco.com



You are here: Home > Projects > SSL Server Test > ca.ovh.com

SSL Report: ca.ovh.com (198.245.48.2)

Assessed on: Tue, 31 Jul 2018 08:48:15 UTC | Clear cache

Scan Another »

Summary

Visit our documentation page for more information, configuration guides, and books. Known issues are documented here.

This server is vulnerable to the Return Of Bleichenbacher's Oracle Threat (ROBOT) vulnerability. Grade set to F. MORE INFO »

This server does not support Forward Secrecy with the reference browsers. Grade capped to B. MORE INFO »

This server does not support Authenticated encryption (AEAD) cipher suites. Grade capped to B. MORE INFO »

Apart from informing vendors and affected sites we also contacted developers of test tools (SSL Labs, testssl.sh, TLS Attacker, tlsfuzzer).

Before ROBOT no easily usable test tool for Bleichenbacher attacks was available.

CTF

1. Decrypt message with vulnerable host.
2. Find second host based on public key with Certificate Transparency
3. Sign message with server key.

Timing

We did not consider timing based side-channels as part of this research.

It's known that some stacks don't implement the timing countermeasures (NSS has an open bug).

But even if you implement PKCS #1 1.5 according to the TLS 1.2 spec...

Crypto is math.

Cryptographic keys, signatures etc. are just large numbers.

Bignums

Cryptographic implementations use bignum libraries that allow numbers of arbitrary size.

Smaller numbers take less memory than larger numbers.

RSA

RSA decryption: M = C^d mod N

Result of this function with standard keysize (2048 bit) is 256 bytes large - usually.

RSA result

Or 255 bytes, or 254, depending on how many leading zeros the result has.

RSA bignum size sidechannel

Operating with smaller result leaves a small timing difference.

Practical?

We don't know.

This affects all major TLS libraries.

David Benjamin has fixed this in BoringSSL and submitted a pullrequest to OpenSSL.

OpenSSL PR #6640

Inconsistent Oracles

Some servers send certificates or "garbage bytes" in response to a bad ClientKeyExchange.

Communigate Pro is the only product we could identify with this behavior but there are others

Bleedinbacher anyone?

There could be a Heartbleed-style memory disclosure waiting to be found.

What to do?

If you run TLS disable TLS_RSA cipher suites.

TLS 1.3 no longer uses the RSA key exchange, but you're still at risk if you support older TLS versions and don't disable TLS_RSA.

Stop using RSA with PKCS #1 1.5!

If you want to use RSA use OAEP/PSS.

Takeaways

- Old attacks still work, you can win a Pwnie recycling a 20 year old attack
- Stop using TLS_RSA ciphers in TLS
- Stop using PKCS #1 1.5