Wombat: one more Bleichenbacher attack toolkit

Olivier Levillain   Aina Toky Rasoamanana

Télécom SudParis

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Plan

RSA and PKCS#1 v1.5 in a nutshell

Bleichenbacher : *the million-message attack*

Wombat : one more Bleichenbacher toolkit

Current results and future work

Conclusion

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RSA 101

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- a pervasive cryptosystem
- asymmetric encryption and signature

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- public key $n = p \cdot q$, e
- private key d
- raw encryption : $C = M^e[n]$
- raw decryption : $C^d = M^{ed} = M[n]$

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- raw encryption : $C = M^e[n]$
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Problems with raw RSA operations

- if e and M are *small*
- malleability w.r.t. the multiplication

The need for a padding scheme

We thus need to format the message before encrypting (or signing) it

- PKCS#1 standardize how to use RSA
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In this talk, we are most interested in padding type 2, described in version 1.5 of the standard, and used for encryption :

$\longleftarrow$ n bytes $\longrightarrow$

00	02	non zero random bytes	00	Encapsulated data

$\longleftarrow$ 8+ bytes $\longrightarrow$

Other padding schemes

PKCS#1 v1.5 also describes two other schemes, which are deterministic

- padding type 0 (zero bytes, rarely used)
- padding type 1 (`ff` bytes, used for signature)

PKCS#1 v2.1

- OAEP (Optimal Asymmetric Encryption Padding) for encryption
- PSS (Probabilistic Signature Scheme) for signature
- these schemes have better security properties...
- ... but are not always used in standards

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An observation about padding type 2

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With a correctly formated message to be encrypted

- the *raw* plaintext M starts with 00 02
- interpreted as an integer, this means that M is an integer between $2B$ and $3B$
  - with $B = 2^{(|n|-16)}$
  - where $|n|$ is the size of the modulus n in bits

Attack principle (CRYPTO 1998)

We assume there exists an oracle which

- accepts to decrypt messages
- returns true when the padding was correct, false otherwise
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An attacker wishing to recover $m = c^d$ can then

- send altered messages $c \cdot s^e$ (with s known)
- let the server handle $(c \cdot s^e)^d = c^d \cdot s^{ed} = ms$
- infer that $2B \leq ms < 3B$ in case the oracle returns true
- repeat the operations, and recover m with these equations
- (this is an adaptive chosen ciphertext attack)

Different oracle types (1/2)

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However, some oracles also make additional checks

- the padding contains at least 8 bytes
- the padding ends with a null byte
- the message obtained has the expected length

Different oracle types (2/2)

If we assume an oracle returning true only for messages

- starting with 00 02
- where the padding contains at least 8 bytes
- and where the padding ends

The attacker thus loses *good* messages (starting with 00 02) which would have led to interesting equations

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Bardou et al. proposed a classification where each oracle type depends on the messages an attacker can distinguish

Results from Bardou et al.

The article, published at CRYPTO 2012, improved the original algorithms (CRYPTO 1998)

Oracle type	Average nb of requests	
	Original algo	Improved algo
FFF	-	18 040 221
FFT	215 982	49 001
FTT	159 334	39 649
TFT	39 536	10 295
TTT	38 625	9 374

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A modular way to implement the attack (1/2)

To test an implementation, we write a *stub*, which allows

- to get the RSA public key
- to get a challenge (an encrypted message)
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The attacker can submit messages for which the plaintext is known, and assess the oracle type

- well formed messages
- messages not starting with 00 02
- messages with a short padding
- messages with an unending padding

A modular way to implement the attack (2/2)

If the attacker can identify *good* messages by observing the implementation behaviour, an oracle has been identified

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- evaluate more precisely the cost of the attack
- attack the implementation to recover the plaintext corresponding to the challenge
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`wombat` currently implements

- the original attack from Daniel Bleichenbacher
- improved versions of the attack (Bardou et al.)
- pure oracles to validate the attacks
- a TLS *stub* TLS (more on this later)

An open-source framework

Wombat

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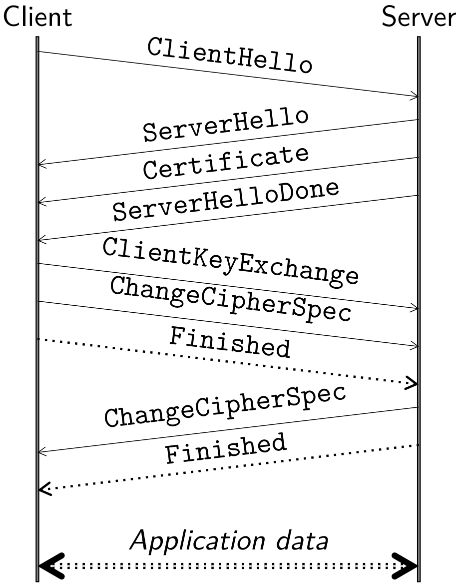
Possible usages

- help identifying existing oracles
- mount attacks (with respect to the law and morality)
- mount hands-on sessions in classes (a simple TCP server is provided)

Plan

Application to TLS (1/3)



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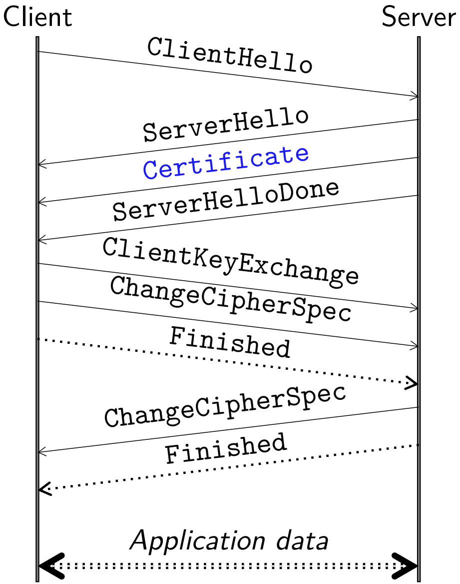

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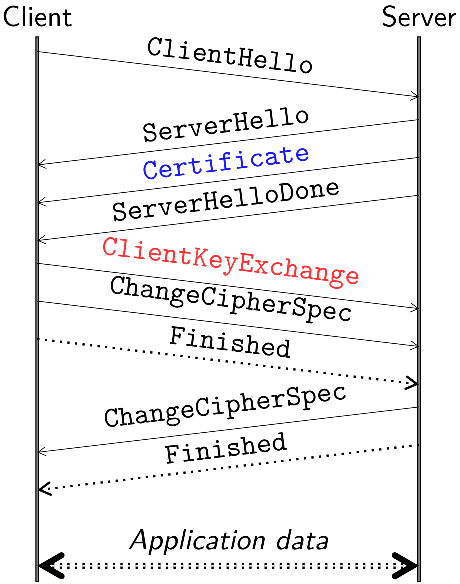

Application to TLS (2/3)

We wrote a *stub*

- public key recovery from the server certificate
- creation of a target ciphertext (the challenge) including a *pre-master-secret*
- interface to send message to be decrypted to the TLS server
    - first messages to force the use of RSA key exchange
    - emission of the `ClientKeyExchange` including the encrypted message to test
    - observation of the server reaction (received messages, delay before an answer)

Identification and exploitation of an oracle

Application to TLS (3/3)

We added the vulnerability to `mbedtls` (the actual implementation is very robust, including against timing attacks)

```
+   // DON'T DO THIS AT HOME
+   if (ret == MBEDTLS_ERR_RSA_INVALID_PADDING) {
+       mbedtls_ssl_send_alert_message( ssl, MBEDTLS_SSL_ALERT_LEVEL_FATAL,
+                                       MBEDTLS_SSL_ALERT_MSG_DECRYPT_ERROR );
+       return (MBEDTLS_ERR_SSL_BAD_HS_CLIENT_KEY_EXCHANGE);
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Demo time

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% python example_BB_TLS_prober.py <tested-server>
Explicit oracle found (type FFT)
   true-signal: set([(False, 21, 51), TLSHandshakeFailed()])
   false-signal: set([(False, None, None), (False, 21, 20)])
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And interestingly, `<tested-server>` is from Top Alexa 1M !

Future work on TLS

Improve the TLS prober to be more reliable and more precise

- improve the interpretation of timing distributions
- handle more messages from the server behaviour (TCP errors for example)
- use different message sequences to trigger a reaction from the server

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Launch campaigns to *identify* potential oracles in a more systematic way

- regular HTTPS Top Alexa 1M scans
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Implement more sophisticated attacks such as DROWN or TLS 1.3/QUIC signature forgery

Other applications

PKCS#1 is present in other standards

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- XML Encryption (proposed to students)
- ~~SSH~~ (RFC 4432 uses OAEP)
- OpenPGP

Preliminary results on gpg

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- an RSA key used for encryption
- an encrypted message
- altered versions of the encrypted messages

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Decryption time...

Preliminary results on gpg

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Decryption time...

- correct format : `Invalid cipher algorithm` or decryption
- padding too short : `Invalid cipher algorithm`
- invalid first bytes : `Wrong secret key used`
- message is only padding : `Wrong secret key used`

It is an FTT oracle ! Hopefully it is rare to be able to submit encrypted files to OpenPGP and observe the error messages.

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Conclusion

The so-called *million-message attack* from Bleichenbacher

- an attack well known for a long time
- a non trivial example to teach cryptographic attacks
- still a reality today ?

Wombat

- an open source tool to test the attack
- helpful to reproduce existing attacks
- extensible via *stubs* to analyse other standards
- useful for hands-on sessions with students

Questions ?

Thank you for your attention

https://paperstreet.picty.org/yeye

https://gitlab.com/pictyeye/wombat