Implementation Flaws in TLS Stacks: Lessons Learned and Study of TLS 1.3 Benefits

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TLS in a nutshell
Protocol description

SSL/TLS is pervasive today
- HTTPS (many use cases)
- A generic method to secure protocols
- SSL VPN, EAP TLS...

Security goals
- Server (and optionally client) authentication
- Data confidentiality and integrity protection
- Anti-replay
A history of vulnerabilities

Since its inception in 1995 as SSL, the protocol has known many problems, especially since 2011.

[bullet points]
- 2011: BEAST
- 2012: CRIME
- 2013: Lucky 13
- 2014: POODLE
- 2014: Heartbleed
- 2014: 3SHAKE
- 2015: FREAK
- 2015: LogJam
- 2016: DROWN

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The TLS 1.3 revolution

TLS 1.3, standardized in RFC 8446, brings many answers to the aforementioned problems

- Most obsolete cryptographic constructions were removed
  - RSA PKCS#1 v1.5
  - MD5, SHA1, RC4
- The handshake phase is more secure
- The forward secrecy is always guaranteed
- Only proper selected groups can be used in the key exchange
- The privacy has been enhanced
  - Part of the handshake is encrypted
  - For encrypted messages, the type is masked and the length can be padded
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What about TLS implementations?
What should a client expect when they propose the following ciphersuites: \texttt{AES128-SHA} \texttt{et} \texttt{ECDH-ECDSA-AES128-SHA}?
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D something else (**RC4_MD5**)
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B ECDH-ECDSA-AES128-SHA
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- a ciphersuite is represented by a 16-bit integer
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- why bother to inspect this byte?
Implementation Flaws

Common programming errors
Common programming errors in TLS

Selection of classical programming errors in SSL/TLS stacks
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Selection of classical programming errors in SSL/TLS stacks

- CVE-2002-0862 (and CVE-2011-0228): BasicConstraints checks (missing check) in Windows (and iOS)
- CVE-2014-1266: Apple's goto fail (dead code)
- CVE-2014-0092: GnuTLS' goto fail (logic error)
- CVE-2014-0160: OpenSSL's Heartbleed (buffer overread)
- CVE-2014-6321: WinShock (buffer overflow) in Windows
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Focus on GnuTLS’ goto fail (CVE-2014-0092)

The bug allows an attacker to circumvent client-side checks regarding server certificates (source: lwn.net, March 2014)

The `check-if-ca` function is supposed to return true (any non-zero value in C) or false (zero) depending on whether the issuer of the certificate is a certificate authority (CA). A true return should mean that the certificate passed muster and can be used further, but the bug meant that error returns were misinterpreted as certificate validations.
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A similar bug was found in OpenSSL... in 2008 (CVE-2008-5077)!

The fix replaces a `if (!i)` with a `if (i<=0)`, where `i` is returned by a function checking a certificate which was interpreted as a boolean without taking into account other values corresponding to error codes.
Lessons learned

Observations

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- sometimes, similar bugs have resurfaced in different stacks several years apart
- we should not put all the blame on the developers
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What about TLS 1.3?

- with regards to these particular bugs, not much...
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Parsing bugs
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- CVE-2009-2408: Null characters in Distinguished Names (ASN.1 Strings) in Firefox (and others)
- CVE-2014-1568: NSS/CyaSSL/PolarSSL Signature Forgery (ASN.1 Length Encodings)
- CVE-2014-3511: OpenSSL downgrade attack (Record splitting)
- 2013: the Alert attack (Record boundaries) in OpenSSL (and others)
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Several implementations exhibited great laxism in the way ASN.1 messages are parsed:

- arbitrary length encoding
- integer overflow in length values

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▶ when applicable, prefer reconstructing a value rather than parsing and validating it
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What about TLS 1.3?

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▶ ... but some cases have been described and disambiguated
Implementation Flaws

The real impact of obsolete cryptography on security
Bleichenbacher (1/2)

RSA PKCS#1 v1.5

- RSA encryption requires a padding scheme
- how should we handle an invalid padding after decryption?

Bleichenbacher attack (1998)

- main idea: send altered versions of a target encrypted message and observe the server behaviour
- if the attacker can distinguish a valid from an invalid padding, he can gather information on the plaintext
- this can be applied to TLS: the so-called "Million Message Attack"
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... and in 2016

- DROWN (*Decrypting RSA with Obsolete and Weakened eNcryption*)
- attacking SSLv2 to recover a TLS pre-master secret
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... and in 2017 with ROBOT (Return Of Bleichenbacher’s Oracle Threat)... and in 2018 with CAT
Similar issues in the symmetric domain

Dangerous or fragile constructions also exist in the Record Protocol (which protects the application data with symmetric cryptography):

- RC4
- the CBC mode used with the MAC-then-Encrypt paradigm
- invalid GCM nonce reuse breaking the integrity protection
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There again, developers must make hard choices to ensure compatibility while keeping their code maintainable and secure...
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Observations

- obsolete crypto can put developers in an impossible situation where they have to choose between modularity, compatibility and security
- the situation always gets worse with time (a.k.a Schneier’s “Attacks always get better”)

Possible solutions

- drop obsolete and fragile constructions as soon as possible
- constrain the standard so that only correct uses are compliant

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The consequences of complex state machines
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In the default setting, all vulnerable servers nevertheless interpreted unsolicited messages, making them exploitable in practice
Shaky state machines

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- CVE-2014-0224: EarlyCCS (*skip key installation*) in OpenSSL
- CVE-2014-6593: Early Finished (*server impersonation*) in JSSE and CyaSSL
- CVE-2015-0204: FREAK (*server impersonation*) in OpenSSL, Apple SecureTransport and Microsoft SChannel and many others
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- maybe SSL/TLS is too complex?

Possible solutions

- test all possible message sequences
- write crystal clear specifications, including a reference automaton
- drop support for old/useless/dangerous versions/options

What about TLS 1.3?

- on one hand, TLS 1.3 simplified the messages
- ... but 0 RTT mode is a complex beast in TLS 1.3
- ... but TLS 1.3 added fake messages to accommodate middleboxes
- ... and we might have to live at least with TLS 1.2 for some time
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Conclusion and Take away messages
Complexity leads to insecurity

Implementation flaws can happen at different levels

Specifications can help avoid complications
  - better and unambiguous message formats
  - up-to-date cryptographic primitives
  - simple and formally-defined state machines

This would lead the standard to constrain implementers
Better languages, tools and methodologies

Several bugs could be avoided by using modern development tools

- modern programming languages
- strict compilers and static analysers
- tests, tests, tests
Beyond TLS 1.3

TLS 1.3 improved some implementation aspects
▶ but it also created new complexities
▶ and previous versions are far from gone

The IETF is currently standardizing QUIC
▶ a new secure transport layer on top of UDP
▶ reusing TLS 1.3
▶ with very complex constructions...
Thank you for your attention

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