DFA on WolfSSL Ed25519

Seminar 11, PB173

Łukasz Chmielewski

CRoCS,
Masaryk University,
chmiel@fi.muni.cz

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May 2nd, 2024

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Outline

1. Introductions on Fault Attacks
2. Recall on Differential Fault Analysis (RSA)
3. Real-world example: fault attacks on WolfSSL

Attack categories

- Fault Injection was already partially covered on seminar 1.
- Even Differential Fault Analysis (DFA) was briefly mentioned, but I will recall it now.

Plan

Attack categories

- Side-channel attacks
  - use some physical (analog) characteristics
  - the target is running in normal conditions
- Faults: use abnormal conditions causing malfunctions in the system
- Micro-probing: accessing the chip surface directly in order to observe, learn and manipulate the device
- Reverse engineering

Types of implementation attacks

Active vs passive:

- Passive i.e. eavesdropping: the device operates within its specification
- Active i.e. tampering: the key is recovered by exploiting some abnormal behavior e.g. power glitches or laser pulses

Invasiveness:

- Non-invasive aka low-cost:
  - power/EM measurements
  - Coldboot attacks: data remanence in memories - cooling down is increasing the retention time
  - Rowhammer – is essentially a fault attack
- Semi-invasive: the device is de-packaged but no direct contact exists with the chip e.g. optical attacks
- Invasive aka expensive: the strongest type is bus probing

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Methods

- Variation in supply voltage i.e. glitching
  - Can cause a processor skip instruction
  - Actively investigated by smartcard industry
  - So-called unloopers were used to activate the infinity loop in PayTV smartcards
- Variation in the external clock: may cause data misread or an instruction miss
- Change in temperature
  - The temperature threshold is defined for which the chip will work properly
  - Can cause changes in RAM content
- White light: photons induce faults
- X-rays and ion beams

Goals

- Insert computational fault
  - Null key
  - Wrong crypto result (Differential Fault Analysis - DFA)
- Change software decisions
  - Force approval of false PIN
  - Reverse life cycle state – PayTV and old phone cards
  - Enforce access rights
  - Break secure boot

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Practical Fault Injection Aspects and what we concentrate on in this lecture

- Most common FI: voltage and EM (due to its price)
  - `https://github.com/newaetech/chipshouter-picoemp`
- Differential Fault Analysis (DFA)
  - We mention a few advanced recent methods that strongly relate to SCA
- Glitching decisions:
  - secure boot
  - obtaining memory dumps
  - enabling debug interfaces

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DFA

- Bellcore attack in 1995
  - Differential faults on RSA-CRT signatures
  - Requires 1 correct and 1 wrong signature
- Attack on DES in 1997 by Biham and Shamir
- Special attacks on AES, ECC etc.
- Fault attacks on key transfer

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DFA on cryptosystems

- Basic DFA scenario:
  - adversary obtains a pair of ciphertexts that are derived by encrypting the same plaintext (one is correct value and the other is faulty)
  - two encryptions are identical up to the point where the fault occurred
  - $\rightarrow$ two ciphertexts can be regarded as the outputs of a reduced-round iterated block cipher where the inputs are unknown but show a small (and possibly known) differential
- DFA on DES
  - the original attack of Biham and Shamir exploits computational errors occurring in the final rounds of the cipher
  - assumes that one bit of the right half of the DES internal state is flipped at a random position

Recall from seminar 1: RSA with CRT

Optimization of computing a signature giving about 4-fold speedup:
$n = p \cdot q$ Signature: $s = m^d \mod n$

Pre-computed values $d_p := d \mod (p-1)$ $d_q := d \mod (q-1)$
$i_q := q^{-1} \mod p$

$s_p := m^{d_p} \mod p$ $s_q := m^{d_q} \mod q$

Garner's method (1965) to recombine s_p and s_q:
$s = s_q + q \cdot (i_q(s_p - s_q) \mod p)$

Where to glitch?

Almost anywhere :-) computations of s_p and s_q.

If error is in s_p then the adversary can recover q as follows: $q = \gcd(n, s - \hat{s})$.

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Plan

Ed25519

- Instance of EdDSA, which was proposed to “fix the unnecessary requirements on randomness” in ECDSA
- Does not depend on a “good” source of randomness, but instead derives a secret deterministically (hashing the msg and a long-term auxiliary key)
- Widely adopted by TLS1.3, Zcash, SSH, Tor, Signal, WolfSSL etc. (check “Things that use Ed25519”)
- Turns out to be easy to attacks in some real-world deployments i.e. WolfSSL

Niels Samwel, Lejla Batina, Guido Bertoni, Joan Daemen and Ruggero Susella: *Breaking Ed25519 in WolfSSL*, CTRSA2018.
Niels Samwel, Lejla Batina: *Practical Fault Injection on Deterministic Signatures: the Case of EdDSA*, Africacrypt 2018.

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Ed25519

Algorithm 1 Ed25519 key setup and signature generation

Key setup.

1: Hash k such that $H(k) = (h_0, h_1, \ldots, h_{2b-1}) = (a, b)$
2: $a = (h_0, \ldots, h_{b-1})$, Private scalar
3: $b = (h_b, \ldots, h_{2b-1})$, Auxiliary key
4: Compute public key: $A = aB$.

Signature generation.

5: Compute ephemeral private key: $r = H(b, M)$.
6: Compute ephemeral public key: $R = rB$.
7: Compute $h = H(R, A, M)$ and convert to integer.
8: Compute: $S = (r + ha) \mod l$.
9: Signature pair: (R, S).

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The Attack

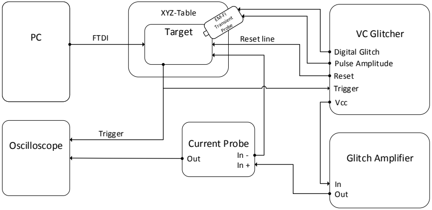
Two signatures, original (R, S) and faulty (R', S'):

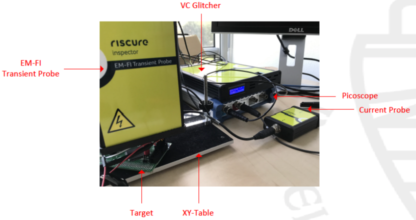
$$S = r + ha$$
$$S' = r + h'a$$

$$S - ha = S' - h'a$$

$$a = \frac{S - S'}{h - h'}$$

Setup


PC
FTDI
XYZ-Table
Target
EM-FI Transient Probe
Reset line
VC Glitcher
Digital Glitch
Pulse Amplitude
Reset
Trigger
Vcc
Oscilloscope
Trigger
Current Probe
Out
In -
In +
Glitch Amplifier
In
Out


VC Glitcher
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Transient Probe
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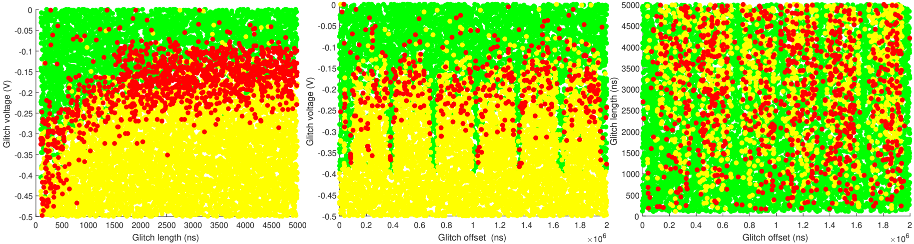
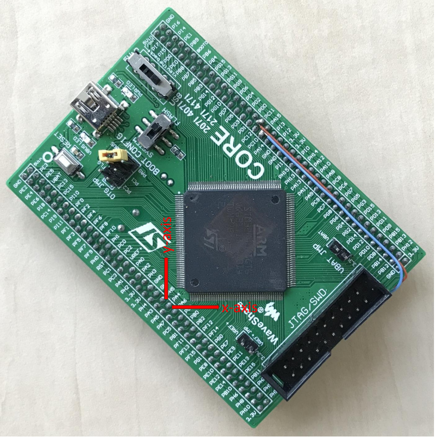
inspector
EM-FI Transient Probe
DELL
Picoscope
Current Probe
Target
XY-Table

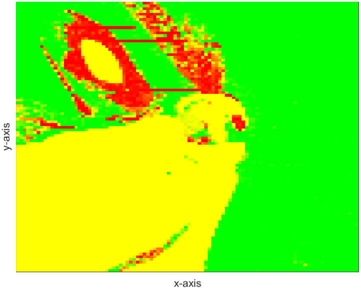
Results



Voltage fault injection results, Normal (green), Inconclusive (yellow), Successful (red).

Results





Conclusion

Two real physical side-channel attacks were actually performed against Ed25519

- Side-channel analysis of Ed25519 with 4 000 traces
- Fault injection on Ed25519 with 100% success rate for EM FI and 70% for voltage glitching out of 10 000 measurements
- For both attacks there exist inexpensive countermeasures

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Questions