Timing Side-Channel Attack

Using linear correlation to reveal secrets

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WE JUST CORRELATE

RSA

Outline

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- these optimizations lead to a linear dependency between time and the data encrypted
- knowing information regarding the time-data pair, it is possible to find a correlation
- this correlation can be used to unveal part of the secret

Hypothesis

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- the HW/SW implementation is known to the attacker
- a timing model can be built

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Bare metal

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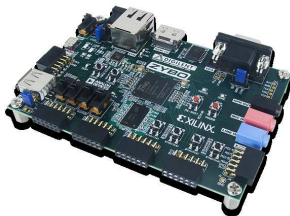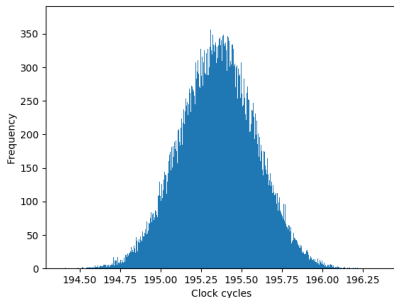
- compile our code for an ARM architecture
- add it to an *Eclipse* project
- used the MAKEFILE generated by Xilinx SDK
- copy the executable on the Zybo board

Finding correlations

PCC: our game changer

In order to find the linerar contribution of each sample in the overall time, we have used the *Pearson Correlation Coefficient* as an estimator. It has proved to be really effective for our needs, working on the realizations of a random variable.

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4. Get rid of fixed threshold by using multi bit analysis and the max of the accumulated PCCs on a common path

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- Error-detection capabilities

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- Tweakable filtering of input data with `#define` parameters

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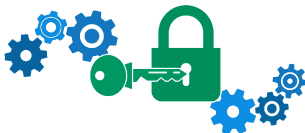
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Even if we mainly worked on the *Zybo* board, we can claim that:

- our attack works also when mounted for other devices, including different architectures (Intel x86, ..)
- with an OS, more tuples (cipher, timing) are needed
- the attack is still feasible

We have completely tested what is mentioned above.

Bigger keys

RSA on 512/1024/2048/4096

The algorithm is capable of handling larger keys on 512, 1024, 2048 and 4096 bits. However, the processing time is longer, and a more complex backtrack might be necessary in some cases.

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- the sections are are listed on the top of each slide, the section the recent slide belongs to is highlighted
- you can automatically receive an outline out of this section by the command

  `\tableofcontents`

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- all this settings have to be done in the preamble of the `presentation.tex` file

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- in connection with `pdflatex` this supports a wider range of graphic formats, including GIF, PNG, JPG

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- bibliography actually works as usual, just keep in mind that not all bibliography styles are supported by the *beamer* package, maybe you have to include some other packages to get your preferred style working

Possible solution

Blinding

The proposed countermeasure is the one given in Kocher (1996). It consists in blinding the message before the encryption using a couple of values v_f, v_i chosen in such a way that:

$$v_i^e \cdot v_f \, mod \, N = 1$$

This contermeasure, in all our tests, has proven to be really effective. Ciphers are completely masked, no correlation can be identified.

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- porting the attack in C++ to keep class structure and speedup w.r. to Python
- find an optimal filter and explain the strange behavior of the implemented filter

References I

Bansal, M., Kumar, A., Devrari, A., Bhat, A., UTU, D., and Dehradun, U. (2015). Implementation of modular exponentiation using montgomery algorithms. *International Journal of Scientific & Engineering Research*, 6(11):1272–1277.

Crockett, L. H., Elliot, R. A., Enderwitz, M. A., and Stewart, R. W. (2014). *The Zynq Book: Embedded Processing with the Arm Cortex-A9 on the Xilinx Zynq-7000 All Programmable Soc*. Strathclyde Academic Media.

Kocher, P. C. (1996). Timing attacks on implementations of diffie-hellman, rsa, dss, and other systems. In *Annual International Cryptology Conference*, pages 104–113. Springer.

Walter, C. D. (1999). Montgomery exponentiation needs no final subtractions. *Electronics letters*, 35(21):1831–1832.

Xilinx (2015). *Zynq-7000 All Programmable SoC Software Developers Guide*. Xilinx.