# FPGA Implementation of SIMON-128 Cryptographic Algorithm Using Artix-7

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*Abstract*—FPGA is a hardware architecture based on a matrix of programmable and configurable logic circuits thanks to which a large number of functionalities inside the device can be modified using a hardware description language. These functionalities must often be secured especially when the context is sensitive (military, banking, medical, legal, etc.). In this paper, we put forward an efficient implementation of SIMON's block cipher algorithm using Xilinx Vivado 2018.2. The proposed design is analyzed through simulation on Xilinx Artix-7. A prototype of our design is implemented using the xc7a35tcsg324-1 FPGA chip. Performance and results are discussed.

Index Terms—Artix-7, SIMON-128, FPGA, Security, Cryptography.

## I. INTRODUCTION

Cryptography [1] has been used for thousands of years. Nowadays, it is more and more present in our daily life. Contemporary cryptography is mainly interested in, but not limited to, the six following properties:

- Secrecy (or confidentiality): the property that ensures that secret or sensitive information is not discovered by an unauthorized party;
- Authentication: the property that ensures that a stakeholder or service requester is who they claim to be, by presenting something they have, something they are, or something they know.
- Integrity: the property that ensures that the information has not been modified in a malicious, accidental, or intentional way by a third party;
- Authenticity: authentication and integrity usually results in authenticity, which is the guarantee that the information is authentic and comes really from its purported source as it is sent;
- 5) Non-repudiation: the property that ensures that a stakeholder cannot deny his action, or his partial participation in an action. This results in the fact that one can always establish irrefutable proof of an stakeholder's action;
- Availability [2]: the property that ensures that the information or service has not ceased to exist in a malicious way.

The ability to keep an encrypted message secret is based not on the encryption algorithm but on a secret piece of information called a key that must be used with the algorithm to produce the encrypted message. The size of the key, expressed in number of bits, is a key element and plays a crucial role in the security of the cryptographic algorithm. Depending on whether the key used for encryption and decryption is the same or not, we speak of a symmetric or asymmetric cryptographic system. Symmetric cryptography, also known as secret key cryptography, uses a unique key to encrypt and decrypt data. This key must be shared with the recipient. The advantage of symmetric cryptography is that it is easy to implement. Its disadvantage is that the secret key must be shared with the recipient, which adds a key management burden. Unlike symmetric cryptography, asymmetric cryptography requires two keys for its operation: first, a so-called public key that must be made public to recipients; second, a private key that must be kept secret. The public key and the private key are two totally different things, nevertheless, they are linked by mathematical bonds. The advantage of asymmetric cryptography is that one does not manage the security of key sharing, but its disadvantage is that it takes a lot of time. Also, encrypted messages are much larger than those encrypted using symmetric keys.

Cryptographic protocols, using symmetric or asymmetric cryptographic algorithms, [3], [4], [5], [6] are rules of exchange between network points whose role is precisely to secure communications. They are used for example in e-commerce, when a customer enters his credit card number to pay for a purchase. But they are also used in a multitude of other situations, such as when connecting to a computer in a secure manner, when sending e-mails if one wishes to prevent an eavesdropper from reading them, or when checking one's bank account balance. They are used for any use of the bank card, such as withdrawing money from an ATM or paying in a restaurant. They have also been used for a long time in the decoders of pay TV channels to allow the customer to have access to the channels to which he has subscribed and to prevent him from accessing other channels, while

allowing possible changes in the subscription. Nowadays, it is possible to implement a cryptographic algorithm in a software or hardware way. The hardware implementation of a cryprographic algorithm consists of the use of computer hardware (e.g. processors, dedicated chips, etc.) in the data encryption process. In general, this implementation is put integrated in the instruction set of the processor, which means that a part of the processor is dedicated to the cryptographic mission. This also means that a significant increase in speed will be observed. By the same stream of ideas, parallel architectures of modern processors are capable of executing other instructions at the same time. A secure cryptoprocessor is a processor optimized for cryptographic tasks (modular exponentiation, DES encryption, etc.) incorporated with multiple physical security measures, giving it some resistance to tampering. It can be realized in various ways depending on the profile of the use: FPGA, ASIC or microcontroller. The reconfiguration capabilities of FPGAs allow considerable optimization of operations and correction of implementations if necessary. Some encryption algorithms are less suitable than others for modern hardware. DES, for example, is based on permutations between bits, which may not be suitable for some types of hardware.

In this paper, we propose a hardware implementation of the SIMON-128 cryptographic algorithm[7], [8], [9], [10]. The architecture we are putting forward is designed using Xilinx Vivado 2018.2. It is implemented on the xc7a35tcsg324-1 Artix-7 FPGA board. Artix-7[11], [12] is a development platform designed around the Xilinx in-situ programmable gate array. It is designed entirely for use as a MicroBlaze softcore processor system. The Artix-7 FPGA is optimized for high-performance logic and offers better performance as well as more capacity than old designs.

The methodology including the SIOMON algorithm description is presented in section II. Design, synthesis, implementation, and experimental results are presented in section III. Discussion is made in section IV. Finally, section V makes conclusions.

# II. METHODOLOGY

The algorithm we implement in this paper is the SIMON encryption algorithm. It was proposed by researchers in cryptography at the NSA. One of SIMON's security goals was to keep a reasonable level of security in an environment where power, memory and processors are severely limited. The detailed description of the algorithm is freely available on the web. SIMON is a symmetric block cipher algorithm. The computation scheme used is a Feistel network[13], [14]. Feistel's process 1 hinges on the idea that repeating judiciously chosen simple operations enough times allows good security. Encryption is a succession of similar steps (called rounds) each using a subkey. This process is characterized by:

- 1) An iterative and modular construction;
- 2) Subkeys are derived from the secret key;

3) The functions used by a lathe must be optimized and are generally simple operations.

These simple operations are generally:

- 1) Permutation: the symbols of the plain text are exchanged between them. Permutation adds diffusion;
- 2) Substitution: a symbol is replaced by another symbol. Substitution adds confusion.

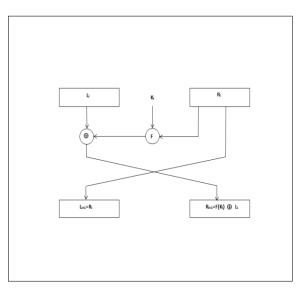


Figure 1. Feistel round.

The encryption is decomposed into several rounds. In each round, two blocks are exchanged and one block is combined with a transformed version of the second block and a key. The transformation function is a non-linear bijection while the combination function is usually the exclusive function (XOR). The rotating key is generated from an initial secret key. The key generation mechanism is usually called a key program. This scheme thus provides the two properties of diffusion and confusion necessary in an encryption algorithm. SIMON is an algorithm intended to be physically implemented in highly constrained embedded systems. For this the following design choices have been made [15], [16], [17]:

- The size of the block and the key are configurable;
- The number of laps required for encryption then varies;
- The nonlinear function used at each turn is very simple;
- The complexity of decryption grows exponentially with the number of rounds.

SIMON respects the symmetry operation regarding the circular shift operation on n-bit words. The key schedule uses a succession of 1-bit round constants devised for the sliding properties and circular shift symmetry.

Table I sums up all configurations of SIMON-128.

Let  $S^j$  denote a *j*-bit-left circular shift. The key schedule is mathematically described as:

The key schedule structure can be either balanced or unbalanced. The number of keywords m is used to establish the key expansion structure, yielding a total bit width of

#### TABLE I SIMON-128 parameters

	Bloc size (bits) key size		key word (m)	Round constant	Rounds
		124	2	$z_2$	68
	128	192	3	$z_3$	69
		256	4	$z_4$	72
{	$c \oplus z_{ji} \oplus k_i \oplus$ $c \oplus z_{ji} \oplus k_i \oplus$ $c \oplus z_{ji} \oplus k_i \oplus$	$(i \oplus S^{-1})$ $(i \oplus S^{-1})$ $(i \oplus S^{-1})$	$\left(S^{-3}K_{i+1}\right)$ $\left(S^{-3}K_{i+2}\right)$ $\left(S^{-3}K_{i+3}\in$	, with , with $\oplus K_{i+1}$ ) , with	m m = 2 m m = 3 m m = 4

m \* n. The keyword expansion consists of a right shift, an XOR and a constant sequence,  $z_x$ . The  $z_x$  bit operates on the lowest bit of the keyword once every round [18], [19].

The SIMON-128 encryption is expressed by Equation 1:

$$R(l,r,k) = \left( \left( S^1(l) \& S^8(l) \right) \oplus S^2(l) \oplus r \oplus k, l \right)$$
(1)

The SIMON-128 decryption is expressed by Equation 2:

$$R^{-1}(l,r,k) = \left(r, \left(S^{1}(r) \& S^{8}(r)\right) \oplus S^{2}(r) \oplus l \oplus k\right) \quad (2)$$

Where l is the left-most word of a block, r the right-most word and k the corresponding round key [20].

# III. IMPLEMENTATION AND EXPERIMENTAL RESULTS

We assume that the block of data to be encrypted as well as the key are presented at the same time. A pulse of the "start" signal indicates that the encryption can start. Once the encryption is finished, the "done" signal goes to one indicating that the value presented on the output "ciphertext" is valid. In addition to these signals, we also have an input for the clock signal "clk" and reset "nrst". The module is divided into three parts:

- SIMON<sub>dp</sub>: for encrypting data blocks;
- SIMON $_{ks}$ : for generating the turn key;
- SIMON<sub>ctrl</sub>: for generating control signals.

The architecture of the SIMON cipher block consists of a parallel cipher that uses round functions and key generation blocks.

The SIMON-128 architecture is implemented on a Xilinx Arty board which is a Artix-7 Pro-based embedded development platform. The xc7a35tcsg324-1 FPGA contains 20800 LUT, 4600 Flip Flip and 9600 LUTRAM modules. We used Xilinx Vivado 2018.2 Softwares to implement our architecture on the board. All VHDL modules are extensively simulated

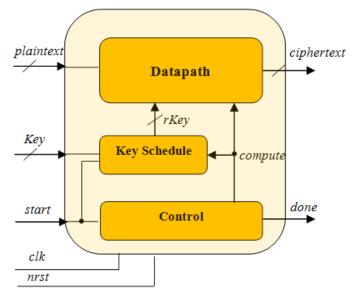


Figure 2. SIMON Design.

using Vivado 2018.2 and synthesized using Xilinx synthesis technologies. Figure 3 shows the experimental setup for the SIMON-128 architecture. Table II presents the implementation resources (Post-synthesis and post-implementation).



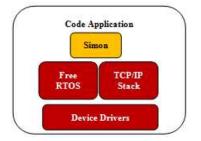


Figure 3. SIMON-Code application using Artix-7.

Summary of on-Chip static and dynamic power are shown in Table III using xc7a35tcsg324 - 1 device of Artix-7 family. Table III and Table IV present the thermal and power characteristics of this implementation.

# IV. DISCUSSION

Table V gives the performance of our implementation and compares it with the results obtained with Zynq-7000 and Virtex-7 presented in [21]. Our implementation presents significant improvement over both of them regarding all metrics.

# Clock signal	
set_property -dict { PACKAGE_PIN E3	IOSTANDARD LVCMOS33 } [get_ports { clk }]; #IO_L12P_T1_MRCC_35 Sch=gclk[100]
create_clock -add -name sys_clk_pin -p	period 10.00 -waveform {0 5} [get_ports {clk}];
#Switches	
set_property -dict { PACKAGE_PIN A8	IOSTANDARD LVCMOS33 } [get_ports { data_in }]; #IO_L12N_T1_MRCC_16 Sch=sw[0]
set_property -dict { PACKAGE_PIN C11	<pre>IOSTANDARD LVCMOS33 } [get_ports { input[0] }]; #IO_L13P_T2_MRCC_16 Sch=sw[1]</pre>
set_property -dict { PACKAGE_PIN C10	IOSTANDARD LVCMOS33 } [get_ports { input[1] }]; #IO_L13N_T2_MRCC_16 Sch=sw[2]
## LEDs	
set_property -dict { PACKAGE_PIN F6	IOSTANDARD LVCMOS33 ) [get_ports { cipher_out[7] }]; #IO_L19N_T3_VREF_35 Sch=led0_(

Figure 4. SIMON-128 XDC file.

TABLE II IMPLEMENTATION RESOURCES (POST-SYNTHESIS AND POST-IMPLEMENTATION)

Resource	Utilization	Available	Utilization (%)
LUT	45	20800	0.22
LUTRAM	12	9600	0.13
FF	27	4600	0.06
ΙΟ	5	210	2.38
BUFG	1	32	3.13

 TABLE III

 ON-CHIP DYNAMIC AND STATIC POWER

Dynamic			Static		
	Power (W)	Percentage		Power (W)	Percentage
Signals	< 0.001	10%			
Logic	< 0.001	13%	PL Static	0.070	97%
I/O	0.001	46%			
Clocks	0.001	31%			

TABLE IV THERMAL AND POWER CHARACTERISTICS

Power	
Total On-Chip Power	0.072 w
Junction Temperature	25.3°
Thermal margin	$59.7^{\circ}$ (12.) w
Effective JA	$4.8^{\circ}$ c/w
Power Supplied to off-hip devices	0 w
Confidence level	Medium

We note a gain in power consumption of 69.87% compared to Zynq-7000 and 70.56% compared to Virtex-7, a gain in delay of 26.69% compared to Zynq-7000 and 8.95% compared to Virtex-7. SIMON Artix-7 also uses less area of lookup table (e.g. 45 LUT) compared to both Zynq-7000 and Virtex-7 (73 LUT). Artix-7 confirms its reputation of being quicker and low-cost than other models.

Other recent work comparable to our present implementation is worthy of mention. For instance, Rashidi in

TABLE V Performance and Comparison of our implementation with Zynq-7000 and SIMON Virtex-7

Metric	SIMON Zynq-7000 [21]	SIMON Virtex-7 [21]	SIMON Artix-7
Power (mW)	239	248	72
Delay (ns)	5.448	4.415	4.020
Area (LUT)	73	73	45

[22] presented an ASIC implementation of several sizes of the SIMON algorithm using Sklansky adder. Encouraging results were observed regarding critical path delay. In the same vein, Sheikhpour et al. in [23] presented a flexible implementation of SIOMON with various key sizes, which has capabilities for various kinds of attacks. In [24], Abed et al. presented several types of SIMON implementations (pipelined, scalar, etc.) and showed a comparison between these families in terms of throughput and drew up an implementation guideline depending on the technological need.

Despite the good performance of our implementation, it requires very sharp knowledge of the hardware and tools and the design is sometimes tedious to set up.

# V. CONCLUSION

In this paper, we have presented an implementation of SIMON-128 algorithm using Artix-7of with low-cost FPGA platform. The Feistel feature of SIMON is chosen to reduce the hardware impact of encryption without sacrificing software performance. Such a structure has the advantage that the encryption and decryption operations are very similar, which is enough to reverse the operation of the key manager to obtain the decryption operation. We used circular offsets (just hardware cabling) and bit-to-bit operations. The implementation led to a good performance that we discussed in this paper compared to other implementations in the state of the art.

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