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Characterization of Physically Unclonable Functions at Design Stage
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Motivation
The evaluation of Physically Unclonable Function (PUFs) quality is an open problem, as the PUF represents a circuit signature which depends on process variation but also environmental conditions. In the literature, some metrics have been introduced. The considered metrics are often the randomness (max entropy), the uniqueness (two PUFs should be different), and the steadiness (Reliability of the result). The objective of our research topic is to propose a new method which allows to evaluate a silicon PUF, based on delay elements, at design stage without the need to have the circuit.

Arbitrifier PUF:
- It is made up of 2^M identical delay elements.
- Each delay element is controllable.
- At the end of the delay path, a DFF is used.

Intrinsic CMOS variation ➔ Delay of two paths is different.
Arbiter is expected to output unique IDs to the Device.

Loop PUF:
- It is based on N delay chains forming a loop.
- Each delay is composed of M controlled delay elements.
- The ID of the device is in relation with the oscillation frequency.

Performance indicators:
- The randomness gives an estimate of the imbalance between the number of IDs at ‘0’ and the IDs at ‘1’ for all the challenges.
- The uniqueness indicates the entropy between two PUFs, either in the same device (intra-uniqueness) or between devices (inter-uniqueness).
- The steadiness expresses the level of PUF reliability which is decayed by the noise coming from the measurement environment.

Background

Our Proposal - Novel metrics

Basics
Classical methods:
- Perform statistical tests on logical outputs of the PUF.
- Need a lot of trials in order to run a Monte-Carlo estimation method.

Proposed method:
- Based on measurement of the physical values (i.e. delays or frequencies).
- The number of tests is linear with M.
- The base of the PUF metrics is to calculate a probabilities.

Randomness

\[ \text{Randomness} = 1 - \left| Pr(D = 0) - Pr(D = 1) \right|, \]

With, \( D_R \) the pdf of \( \sum_{i=1}^{M} d_{t_i} \)

\[ \text{Randomness} = 1 - |\exp\left( \frac{E(D_R)}{\sigma \sqrt{2 \cdot M}} \right)|, \]

Uniqueness

\[ \text{Uniqueness} = \frac{1}{M} \sum_{i=1}^{M} Pr(D_i = D), \]

We consider:
- L PUFs.
- A delay difference distribution \( D \) for \( M \cdot L \) delay elements.
- M normal distributions \( D_i \), i in \([1,M]\), of \( L \) elements in the same range i.

Steadiness

\[ \text{Steadiness} = 1 - Pr(\text{error}), \]

\[ Pr(\text{error}) = Pr(\text{error} | \text{delay} < |\lambda|) \cdot Pr(\text{delay} < |\lambda|). \]

Every delay difference of element i is measured T times.

\( D_i(\{s\}) \) is the distribution of each element for T tests.

Distribution of mean values \( D(\{\sigma\}) \)

Error window \([-\lambda,\lambda]\).

Experiments and Results

Experiments:
- Tests have been carried out in a CYCLONE II EP2C35F672.
- The placement/routing of all delay chains has been constrained to obtain the exact replication of the same chain. This is possible in ALTERA.

Results:

<table>
<thead>
<tr>
<th>Performance indicator</th>
<th>Arbitrifier PUF</th>
<th>Loop PUF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Randomness</td>
<td>0%</td>
<td>100%</td>
</tr>
<tr>
<td>Intra-Uniqueness</td>
<td>97.83%</td>
<td>95%</td>
</tr>
<tr>
<td>Steadiness</td>
<td>99.07%</td>
<td>98.7%</td>
</tr>
</tbody>
</table>

Conclusion & Future Research

Conclusion:
- Novel metrics for evaluation and characterization delay PUFs has been proposed.
- These metrics have been validated on an FPGA.

Future Research:
Since this method allows PUF designer to characterize her PUF at design stage and without the need to have the circuit, measurements can be realized with a simulator such as ‘Spectre’. Process variation can be done using Monte-Carlo simulation. Environmental variation can also be simulated. Then, results of simulation will be compared with ASIC results.

References