# Authentication using DRAM PUFs

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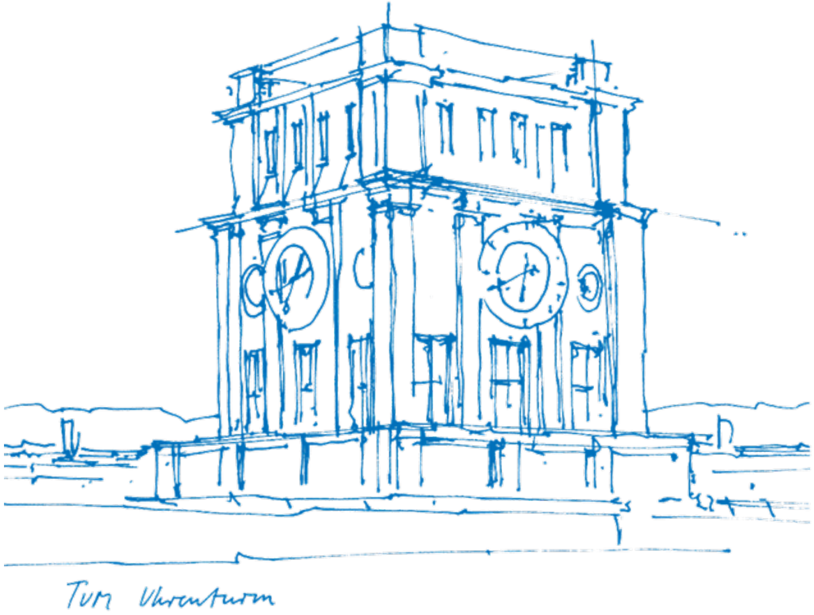

# Overview

Motivation

Basics of PUFs and DRAM PUFs

Authentication for Strong PUFs

Authentication for Weak PUFs

Conclusion/Summary

# Motivation

*"Security and privacy concerning embedded devices connected to the internet is increasing..."*

- **Top Concern:** Counterfeit and tampered hardware.
- Traditional solutions do not completely solve the problem
  - ROM keys - Can be physically extracted by intrusive methods and cloned.
- This demands hardware-intrinsic security mechanisms which are **physically unclonable**
- Physically Unclonable Functions a.k.a PUFs

# Basics - PUFs

**Definition (Physically Unclonable Functions)**

A physical object that takes an input(challenge) and provides a response that is **unique** to the object.

- Each PUF instance is able to create a set number of challenge-response pairs depending on its physical characteristics.
- Strong PUF: Large CRP Database
- Weak PUF: Small CRP Database
- PUF constructions need to be hardware-intrinsic. Hence, they usually take advantage of manufacturing variations for uniqueness.
- Ex. DRAM based PUFs, SRAM based PUFs etc.

# Basics - DRAM based PUFs

- **Startup:** The startup state of the DRAM is used for unique fingerprinting.
  - DRAM are precharged to vdd/2 sense amplifier equally likely to read a ‘1’ or ‘0’.
  - Due to the manufacturing variations there is a **bias**.
- **Write Failures:** Process variations affecting the write reliability are exploited.
  - The duty cycle is deliberately reduced which results in some DRAM cells being overwritten while others are not.
  - The data being written can be treated as the challenge and a subsequent read reveals the response affected by the variations.
- **Refresh Pause:** The refresh of the DRAM cells is paused.
  - Random decaying of the data stored in memory based on the manufacturing variations.
  - The data stored before the delaying refresh can be treated as the challenge and the one after the delay as the response.

# Adversary and Threat model

- A client/prover (C) device wants to authenticate itself a server/verifier (S).
- It is assumed that all network traffic between client and server is observable by attackers except **Enrollment** and **Characterization** phases.
- The attacker might have physical access to the but cannot use it for its intended purpose before authentication.
- The server is assumed to be honest in most settings except **Mutual Authentication**

# Enrollment

- The enrollment phase deals with the generation of the CRP database.
- Stored on a trusted secure database or distributed to verifiers in a secure manner.
- **NOTE:** different verifiers receive different parts of the CRP database, otherwise one can spoof to be the device to the other.

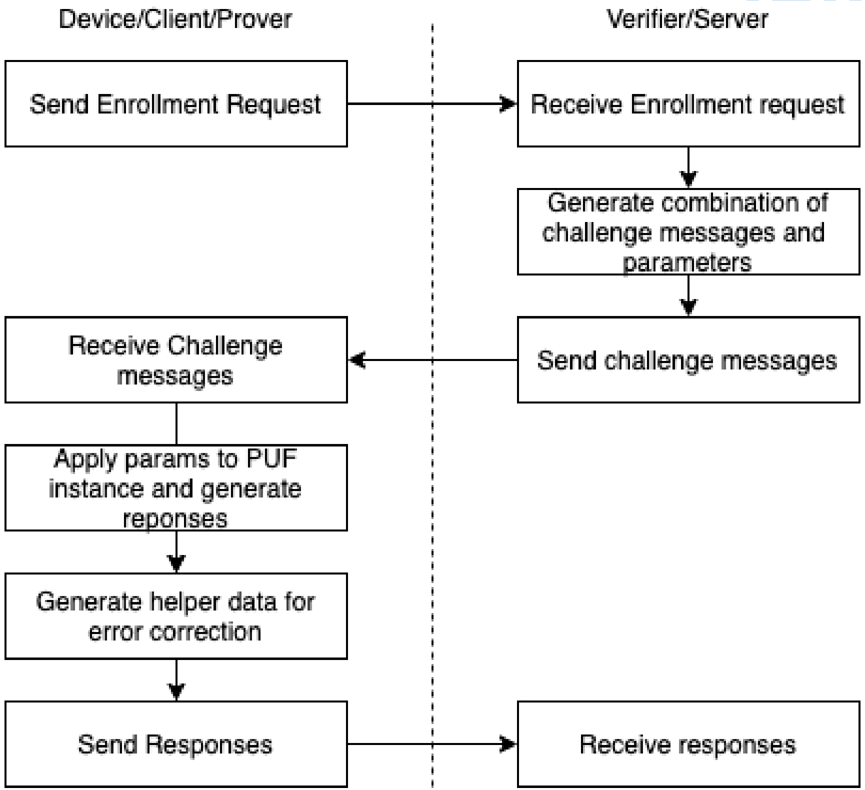


Figure: Enrollment

# Simple Authentication

- The device remeasures a response on obtaining a challenge from the server.
- The server matches the device's remeasured response against the CRP database.
- If they matches, the device is authenticated

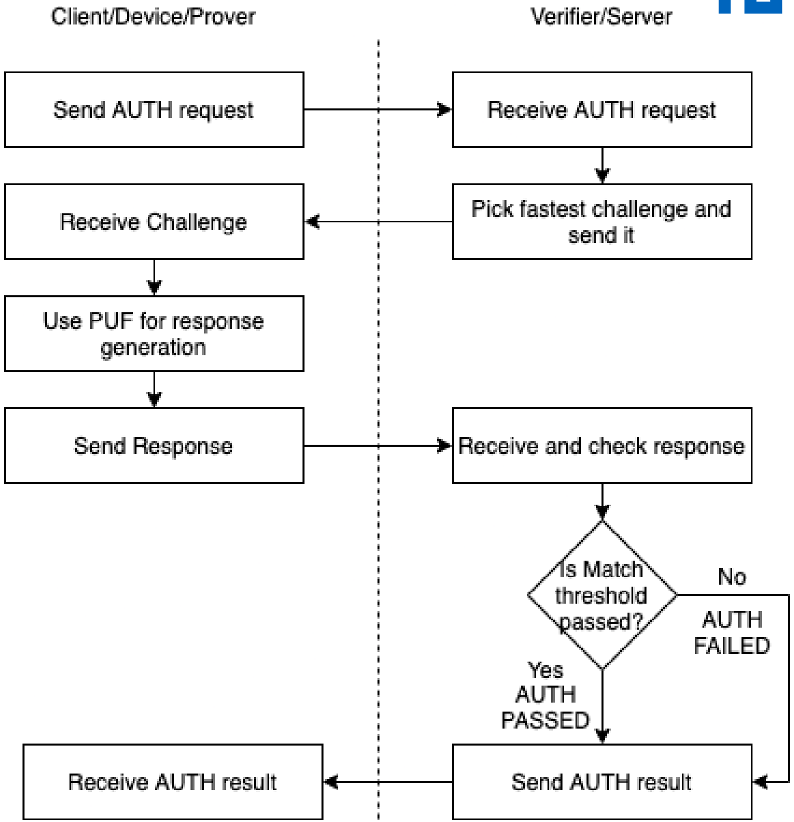


Figure: Simple Authentication

# Mutual Authentication

- Requires the storage of CRPs in form of addresses of flipped bits rather than the bit pattern itself.
- The device mixes random addresses with the flipped addresses before sending the response
- The server verifies the device if the number of matched addresses and checking is above a threshold.
- The server then filters out the known flip addresses from the response and sends them to the device.
- The device verifies the server's response by matching it with its own response.

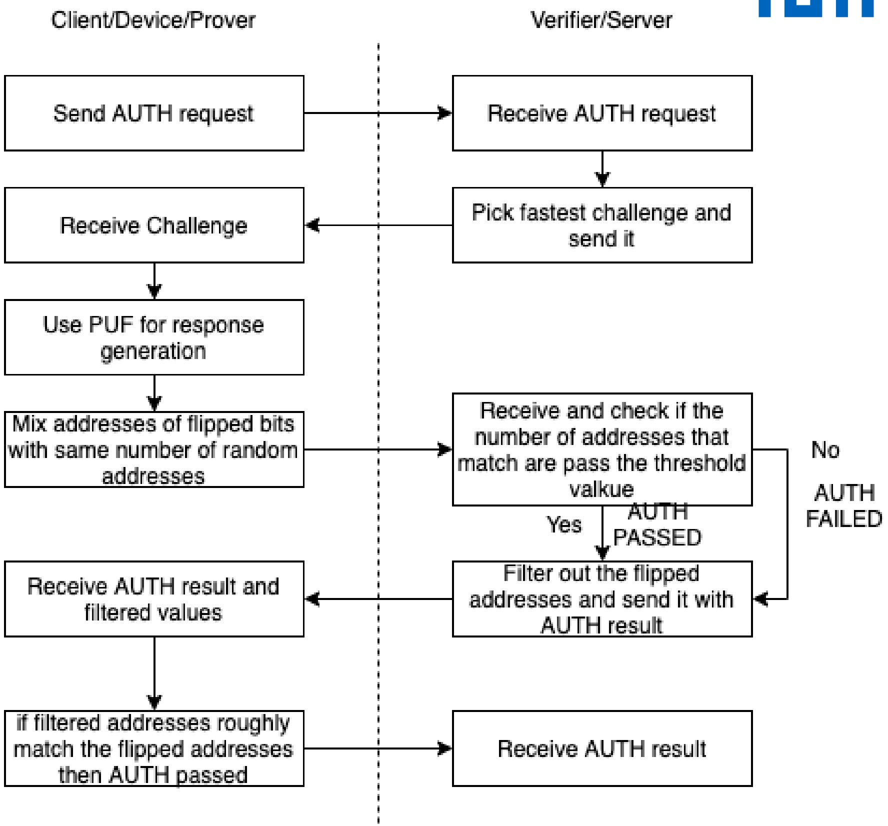


Figure: Mutual Authentication

# Reconfigurability and Characterization

- A CRP is never used twice to prevent replay attacks. Hence you will need a large CRP database.
- **Parameter Reconfigurability** allows changing parameters from the same PUF instance and regenerating a new CRP database on it.
- Current implementations are slow, faster physical parameters are needed.
- **Characterization** exhaustively measures PUF behavior in different conditions and selects the fastest parameters to generate a response. 6x improvement.

# Authentication for Weak PUFs

- Since weak PUFs cannot be used for simple authentication.
- Used with Fuzzy Extractors a.k.a Helper Data Systems for secure key storage.
- A fuzzy extractor corrects errors in the PUF response and enables regeneration of a cryptographic key.
- The stored key then be used to establish a secure channel for authentication

# Fuzzy Extractors

- *Enrollment Algorithm:* The enrollment algorithm takes as input a PUF response $X$ and a random cryptographic key $k$ and outputs helper data $w$.
- *Reconstruction Algorithm:* The reconstruction algorithm takes as input a fresh and noisy measurement of the PUF response $X'$, and helper data $w$, and outputs a reconstructed key $k'$. If the noise in the PUF response is within a threshold $k' = k$

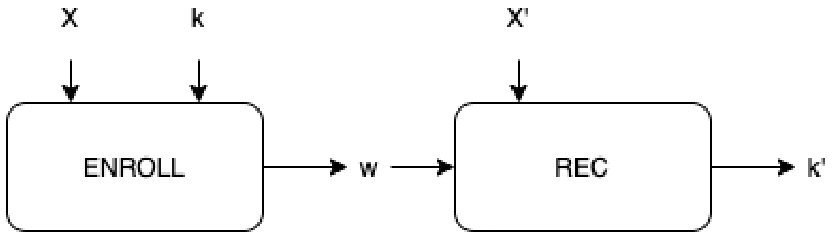


Figure: Enrollment

# The Code Offset Method

- One of the earliest implementations of fuzzy extractors.
- COM uses an error-correcting code at the core of its construction.
- **Enroll:** $w = X \oplus Enc(k)$
  - $Enc()$ is the encoding function of the error-correcting code.
- **Reconstruct:** $k' = Dec(X' \oplus w)$
  - $Dec()$ is the decoding function of the error-correcting code.

## Error Correction Magic

Rewriting the reconstruction formula as $k' = Dec(X' \oplus X \oplus Enc(k))$ shows us that any remaining error bits introduced by $(X' \oplus X)$ is corrected by $Dec()$. $w$ plays the role of a syndrome.

# Syndrome-COM

- Syndrome-COM or SCOM leverages syndrome decoding to use the input, $X$, itself as the cryptographic key.
- This is done by setting the helper data to the syndrome of $X$.
- **NOTE:** Requires sufficient entropy in the input $X$ to not leak information through helper data, $w$.
- Schaller et al overcome this problem by randomly arranging the order of flipped addresses.

**Algorithm 1** Enroll

1: Measure $X \in 0, 1^n$
2: Compute helper data $W = SynX$.
3: Publicly store $W$

**Algorithm 2** Reconstruct

1: Read $W$
2: Measure $X' \in 0, 1^n$
3: $\hat{\mathrm{X}} = X' \oplus SynDec(W \oplus Syn(X'))$

## Error Correction Magic

Rewriting the reconstruction formula, $(W \oplus Syn(X'))$ is just equal to $Syn(X + X')$. So the syndrome decoder extracts the error bits out from X'. This when XORed with $X'$ will give us the required cryptographic key X $\hat{=}$ $X$

# Other FE Constructions

## Concatenated Codes as FE

Make use of concatenation of two linear codes, $C_1 = [n_1, k_1, d_1]$ and $C_2 = [n_2, k_2, d_2]$
Code $C_1$ needs to maintain a high entropy, which directly translates into high cardinality or high $k_1$.
Code $C_2$ needs to have a high error correction rate which directly translates to higher distance, $d_2$.

- It is obvious that we need high input entropy. For this, We cannot increase the codeword size due storage constraints.
- So we increase $k$ but the error correction of the code $C_1$ takes a hit due to the singleton bound.
- To the offset this we concatenate a second code $C_2$ with better error correction capability or high $d$

# Questions?

# PUF Implementations Objectives

- **Uniqueness** in PUFs is measured by comparing responses for the same challenges on different PUF instances. A greater difference in responses indicates stronger uniqueness. This measurement can be using either Hamming Distance or the Jaccard Index.
- **Robustness** of a PUF is measured by comparing the responses for the same challenges on the same PUF instances but on consequent executions. Hence robustness, in this context can also be seen as **reproducibility**. Reproducibility is also checked in varying temperatures and against aging.
- **Run-time access** is required for convenient authentication of the device alongside a running OS. Startup based methods are hence inconvenient because they only provide boot time access. Other approaches use a separate module/memory controller or use selective memory refreshing.

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