Post-quantum secure PUF authentication using LPN

Han Zhao, May 9, 2017

Fraunhofer

AISEC

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Introduction
- Concept
- Motivation

The construction of the authentication system
- Enrollment phase
- Authentication phase

Conclusion

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Introduction
Concept

LPN: Learning Parity with Noise

1. Randomly select a secret s in GF(2)
2. Randomly select A from GF(2)
3. Select a bit offset e $\longrightarrow Ber_\epsilon$
4. Output b= $<$ A*s+e $>$ as a sample

$$b_i = A_i{}^*s + e_i \mod 2 \quad \text{with i=0,1,...,m}$$

The goal:

Find s given only the values of b and A.

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Introduction
Motivation

- Fundamental in theory for LPN
  - Equivalent to decoding random linear codes
  - Believed to be hard

Motivation
LPN – Problem

Solving LPN-Algorithms	Time Complexity(t)	Query Complexity(n)	Example: n=128, ε=0.5
BKW[1]	$2^{\Omega(\frac{n}{log n})}$	$2^{\Omega(\frac{n}{log n})}$	$2^{60.75} / 2^{60.75}$
Lyubashevsky[2]	$2^{\Omega(\frac{n}{log log n})}$	$n^{(1+\varepsilon)}$	$2^{395.42} / 2^{19.80}$
The best algorithm[3]	$2^{\Theta(n)}$	$\Theta(n)$	$2^{128} / 2^{7}$

Introduction
Motivation

- Many applications in Cryptographic
  - User authentication, encryption, etc
  - Cryptographic primitives

Strong PUF-authentication:

— information-theoretical complexity

— no protection mechanisms

— not post-processed on chip

LPN-authentication:

— computational complexity

— no known quantum-attacks

— post-quantum cryptography

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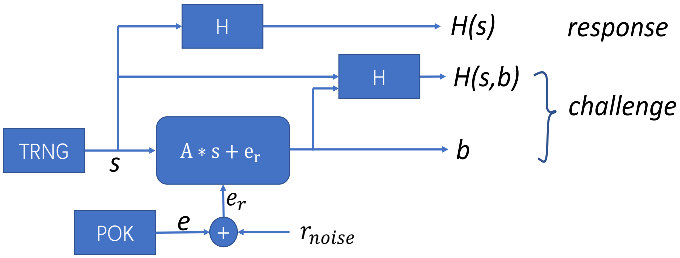
The construction of the authentication system
Enrollment phase

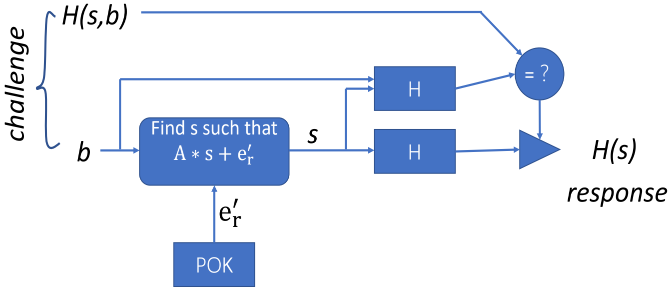


Gen:

random s + one-time-pad → unique b

The construction of the authentication system

Authentication phase



How to extract correct s?

The construction of the authentication system
Authentication phase

Extracting s in the decoding module:

- Gaussian elimination algorithm
  - suitable for linear equations
  - complex implementation in hardware
- Error correction algorithm
  - accurate extraction
  - no security reduction

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Authentication phase
Error correction codes

LDPC Code

- complex construction of PC matrix
- complex encoding module
- suitable for long code

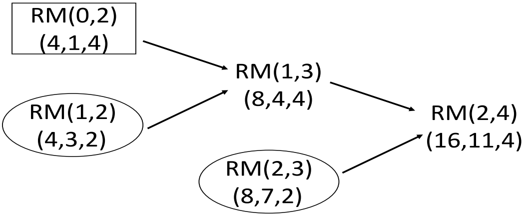
Reed-Muller Code

- the simple construction
- no parity check matrix
- good error correction property

Reed Muller Code

The Plotkin-Construction[4]

Plotkin construction with two subcodes for RM(r,m):



c = $(u \,|u + v\ )$: u ϵ RM(r,m-1), v ϵ RM(r-1,m-1)

Decoding Algorithm
GMC algorithm VS Recursive algorithm

GMC Algorithm:

analysis for AWGN-channel

complex to realise in hardware

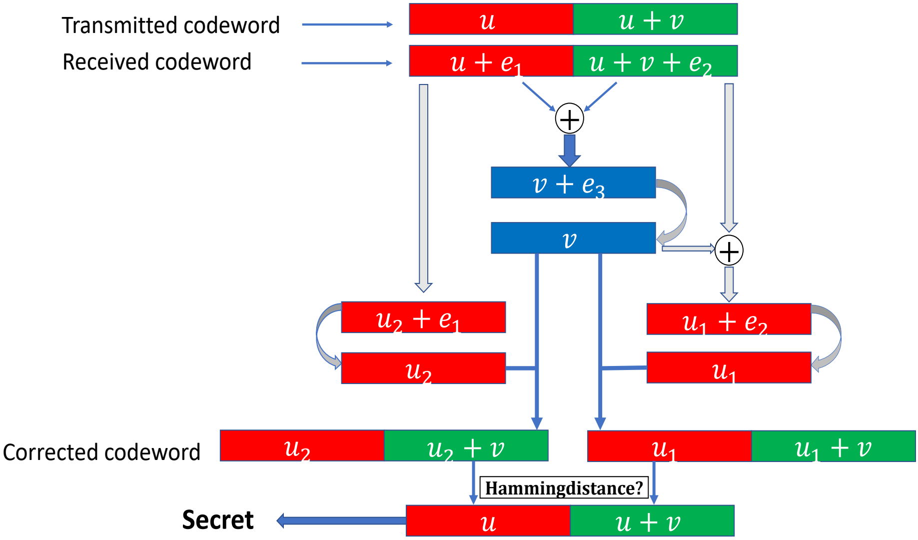
Recursive Algorithm:

analysis for BEC

easy to operate in hardware

Reed Muller Code

The Recursive Decoding Algorithm[4]



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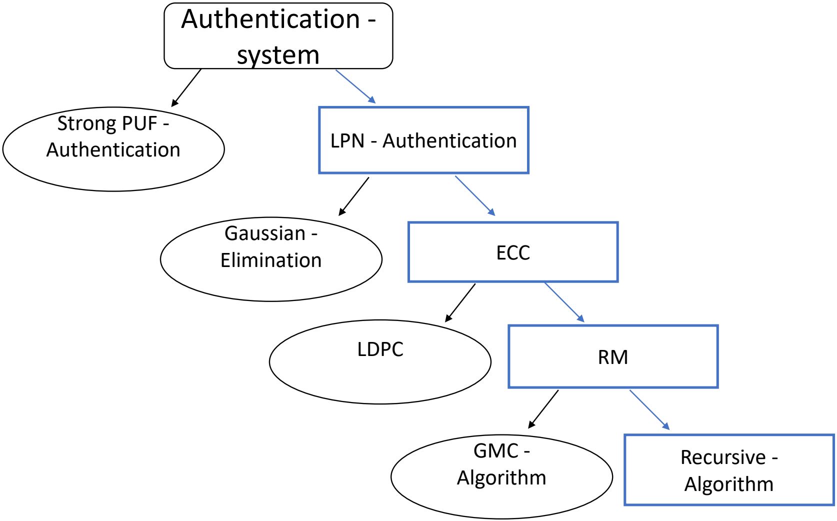
Authentication - system
Strong PUF - Authentication
LPN - Authentication
Gaussian - Elimination
ECC
LDPC
RM
GMC - Algorithm
Recursive - Algorithm

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WBS	Name	Start	Finish	Work
1	Implementation in software(Python)	May 1	May 15	15d
2	Design the hardware structure of encoder	May 15	May 17	3d
3	Implementation of encoder (VHDL)	May 18	Jun 2	14d
4	Implementation of hash function(VHDL)	Jun 5	Jun 9	5d
5	Design the hardware structure of decoder	Jun 10	Jun 18	9d
6	Implementation of decoder(VHDL)	Jun 19	Jul 21	25d
7	Implementation of the rest part(VHDL)	Jul 22	Aug 4	12d
8	Writing master paper	Jul 10	Sep 1	40d

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Question?

Post-quantum cryptography

Post-quantum cryptography:

- refers to cryptographic algorithms (usually public-key algorithms)
- secure against an attack by a quantum computer.
- distinct from quantum cryptography, which uses quantum phenomena to achieve secrecy and detect eavesdropping

Weak PUF vs Strong PUF

Weak PUF:

key generation
input and output with same length
a small number of CRPs

Strong PUF:

authentication protocol
long input, short output
large enough CRP space

Security parameter

for this system a key size of n :

- each of the 3 famous algorithms performs worse than brute-force or does not succeed at all[5].
- for a security parameter of k= 128 against the best known attacks.

Parameter setting

for this system a key size of n :

- Plan A: 2 * RM(3,7) (128,64,16)
- Plan B: 1 * RM(3,9) (512,130,64)

Contact Information

Han Zhao

Group Product Protection
Department Security and Trusted OS

Fraunhofer-Institute for
Applied and Integrated Security (AISEC)

Address: Parkring 4
85748 Garching (near Munich)
Germany
Internet: http://www.aisec.fraunhofer.de

Phone: +49 16 25231418
Fax: +49 89 3229986-222
E-Mail: ga84fif@mytum.de

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