



Controlled
Randomness

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Kluczniak,
Kutyłowski

Problem

Idea

Schnorr signature

DH

PACE

Security

Mallet

user

device

Controlled Randomness – A Defense against Backdoors in Cryptographic Devices

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MYCRYPT -Paradigm Shifting Cryptography 2016,
Kuala Lumpur



Role of randomness

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Randomness in cryptographic protocols

- most signature schemes, even deterministic ones (key generation, padding, . . .)
- challenge-response protocols
- DH key agreement
- . . .

removing randomness from crypto seems to be as difficult as building post-quantum systems (or even more difficult)



Catacrypt and randomness

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What if randomness source not ideal?

- while designing a scheme one concerns the randomness a ideal one
do ideal sources exist in reality?
- what happens if the randomness is not ideal?

Catacrypt

advances in attack technology leading to severe failure of cryptography

- is catacrypt a **potential future**, or ...
- ... it has **already happened?**

Randomness and secure devices



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current approach

- if possible **implement in black-box hardware**
- **tamper-evident** or **tamper-proof** devices
- randomness **tests/ certification / inspection by authorities** to ensure proper design

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problems with certification /audit

- requires insight into industrial secrets
- tedious and expensive
- not verifiable by an end-user
- the manufacturer, the certification body and supervisory authorities may collude against a user

From the point of view of an end-user accepting certification result is **based on trust and not on evidence**

local verifiability

the user should be able to check whether device security level is relevant for a concrete application



Threats

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Hardware Trojans

- inspection of the chip under microscope, layer by layer, does not reveal any inconsistency with the implementation documentation
- ... yet the randomness in some sense predictable by the attacker

Kleptographic code

- malicious cryptography
- deviations from the protocol but undetectable for the user
- e.g.: subsequent choices of random numbers entangled in a cryptographic way – an adversary holding a secret key may exploit it



RNG versus PRNG

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True Random Number Generator (RNG)

- based on physical effects
- hard to build a source with uniform distribution
- even harder to test:
 - regular randomness tests detect major failures
 - useless against malicious constructions

recommendations

- not to be used alone
- use together with PRNG as a source of extra randomness



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Pseudorandom Number Generator (PRNG)

- verifiable – set the seed and check the output
- but how to initialize the seed?



Options for setting the seed

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option 1: the manufacturer **installs** the seed,
no protection against malicious manufacturer

option 2: the user creates the seed by starting a procedure
executed **internally** by the PRNG

the process might be a fake – the same concerns as for
option 1

option 3: the **user** uploads the seed to the PRNG
the user is also a potential adversary and may try to get
access to the secrets from the device



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option 4: the user uploads a **part** of the seed while the second part of the seed is installed by the manufacturer, **how to check that each part is used properly?**

option 5: the user and/or the manufacturer uploads the seed, however, during its operation the PRNG modifies its state according to some number of **entropy** bits.
the changes may gradually convert into a seed predictable by the adversary



PRNG

security situation

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Current situation

no guarantees that the PRNG is secure *by-design*

an adversary may know/guess/predict its internal state

Our goal

find effective countermeasures

but avoid rebuilding cryptography from scratch – no time, no resources available



Scenarios to use random numbers

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- option 1** choose random r and make it available to other participants
explicitly or implicitly addressed in the literature
- option 2** choose random k , compute $r := g^k$ and present r the other party in the protocol
our focus
- option 3** choose random r and use it deterministically but not present it to other parties
a challenging problem, e.g. RSA key generation process



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Idea

- the output of PRNG not used directly but subject of deterministic modification based on blinding key set by the user
- user gets control data from the device
- control data not forwarded to other protocol participants



Device setup

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- a PRNG P with a seed y installed by the manufacturer
- a *blinding factor* $U = g^u$ installed on the device by its owner
- u never exposed to the device



Generating r

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- k_0 is taken as the output of P ,
- $k_1 := \text{Hash}(U^{k_0}, i)$,
 - Hash is a cryptographic hash function with results in the range $[0, q - 1]$
 - i is a counter
- $r' := g^{k_0}$,
- $r := (r')^{k_1}$



Verification of r

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On input r and control parameters (r', i) , the user performs the following steps:

- $\lambda := \text{Hash}((r')^u, i)$
- if $r \neq (r')^\lambda$, then consider the device as *faulty* or *malicious*.

note that $(r')^u = (g^{k_0})^u = (g^u)^{k_0} = U^{k_0}$
(kleptographic trick by Young and Yung)



Schnorr Signature

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setup: private key x and public key $y = g^x$

signature creation:

$$k := \text{prng()}, \quad r := g^k$$

$$e := \text{Hash}(m || g^r)$$

$$s := (k - x \cdot e) \bmod q$$



Schnorr Signature with controlled randomness

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$$\begin{aligned}k_0 &:= \text{prng}() \\r' &:= g^{k_0} \bmod p \\k_1 &:= \text{Hash}(U^{k_0}, i) \\k &:= k_0 \cdot k_1 \\r &:= g^k \bmod p \\e &:= \text{Hash}(m || g^r) \\s &:= (k - x \cdot e) \bmod (p - 1)\end{aligned}$$

- (s, e) is the signature,
- the control data are (r', i)

Example: Diffie-Hellmann with controlled randomness

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the device A of Alice executes the following operations:

- 1 choose k at random (take the output from the PRNG),
- 2 $preY_A := g^k$,
- 3 $k' := \text{Hash}(U^k, i)$,
- 4 $Y_A := (preY_A)^{k'}$,
- 5 $y_A := k \cdot k' \bmod q$, where q is the order of the group used

Y_A is presented by the device A together with $preY_A$ and i

Example: PACE with CR

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Card	Controller	Reader
holds: password π counter i	password π	holds: password π entered by the Card owner
<i>Card Setup with the Controller</i>		
	choose $u, v, w, d < q$ at random $U := g^u, V := g^v,$ $W := g^w, D := g^d$	
	← U, V, W, D	
install U, V, W, D	retain u, v, w, d for control purposes	

Example: PACE with CR

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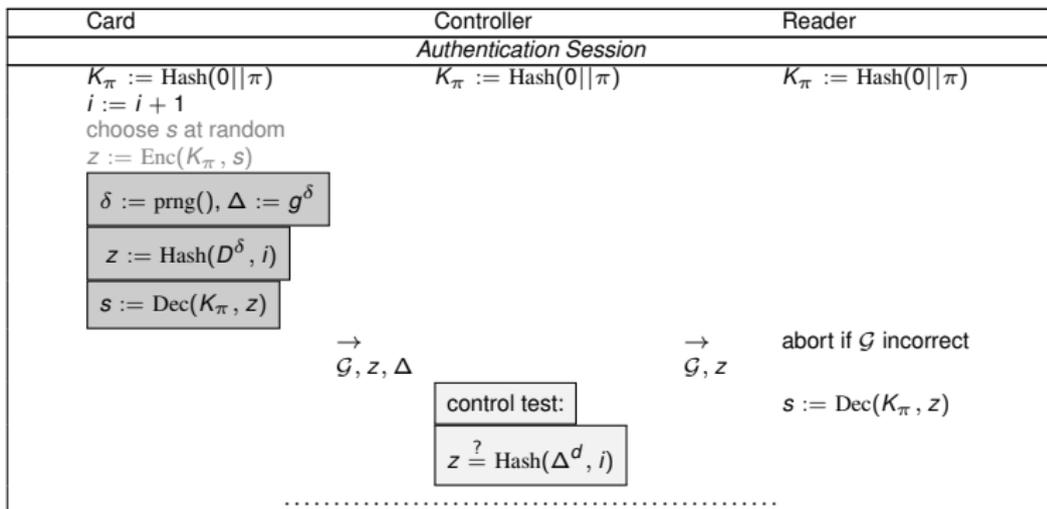
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Example: PACE with CR

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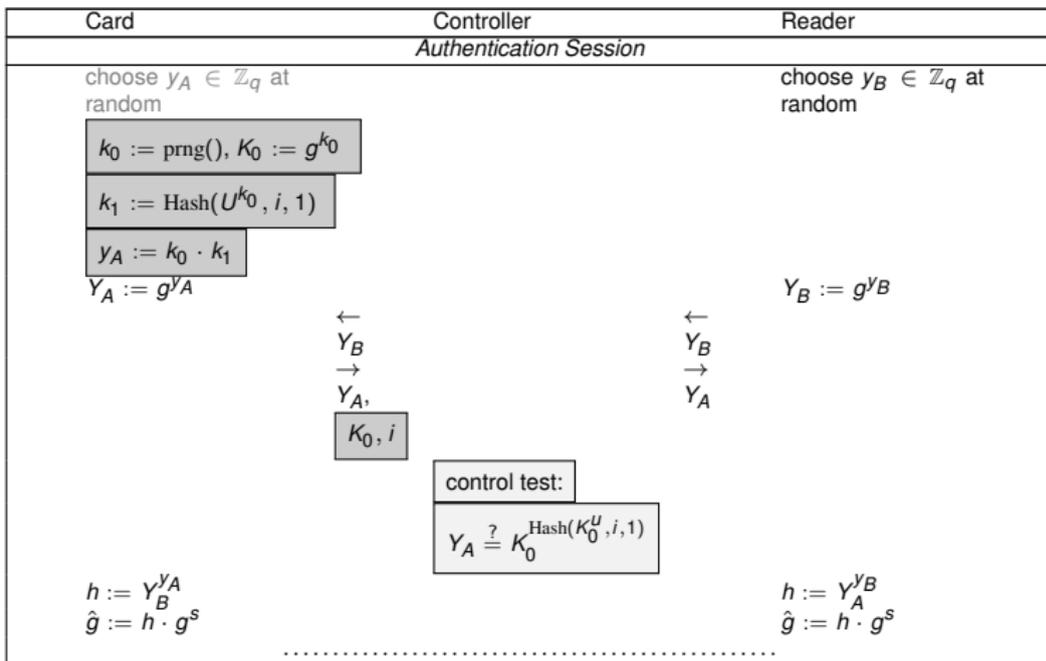
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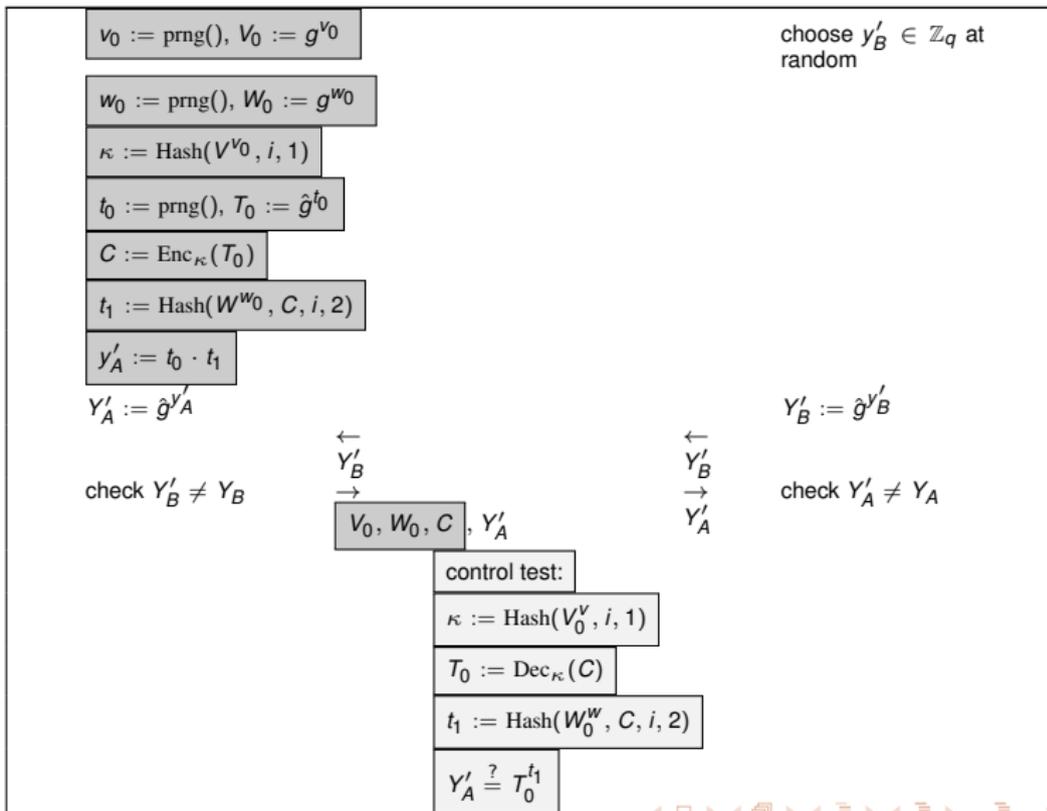
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$$K := Y_B' y_A'$$

..... *FINAL STAGE*

$$K := Y_A' y_B'$$



Manufacturer Mallet

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Assumptions

- Mallet knows output of PRNG
- he does not know the blinding key

Theorem

Mallet **cannot distinguish** between Schnorr signatures created by a device implementing CR from the Schnorr signatures created with the same signing key by a device with the standard implementation (no CR).

In the first case Mallet is given the output of the PRNG, in the second case Mallet is given a random output.



Malicious user

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Threat

potentially the user may steal own key **as he gets more output** from the signing device.

Theorem

If there is a user that holds a device with CR **and then can create a valid signature without the device**, then **the same holds for the regular Schnorr signatures**.



Malicious device

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Leaking key-bits in the regular case

- random components might be correlated via kleptographic techniques
- few bits leaked with each signature if the device has time to make a few trials

Proposition

Assuming KEA1 this is the only way to cheat.

Final remarks

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- a user gets a **real opportunity** to check his devices
- it is **relatively simple** to make the changes in simple protocols
- for protocols where **the generator is changed** in a cryptographic way (like for PACE) the situation becomes complicated (protocol changes, proofs)



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Thanks for your attention!

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