

Swoosh: Efficient Lattice-Based Non-Interactive Key Exchange

Phillip Gajland^{1,2} & Miguel Quaresma¹

¹ Max Planck Institute for Security and Privacy

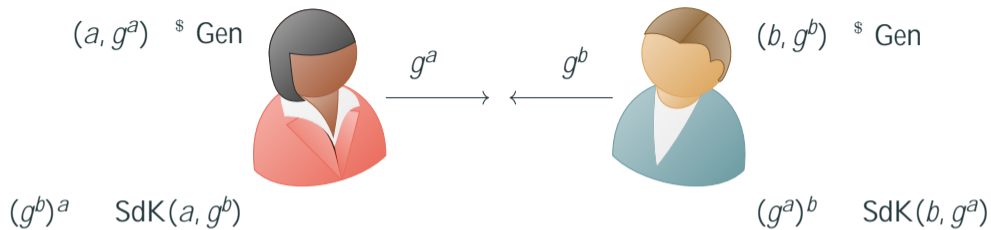
² Ruhr-University Bochum

RWC 2024: Real World Crypto Symposium, Toronto, Canada

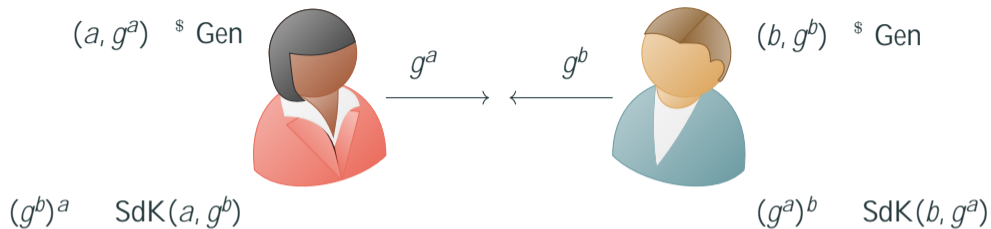


Based on a [USENIX 2024](#) paper with the same title [GdKQ⁺24].

replacing diffie-hellman

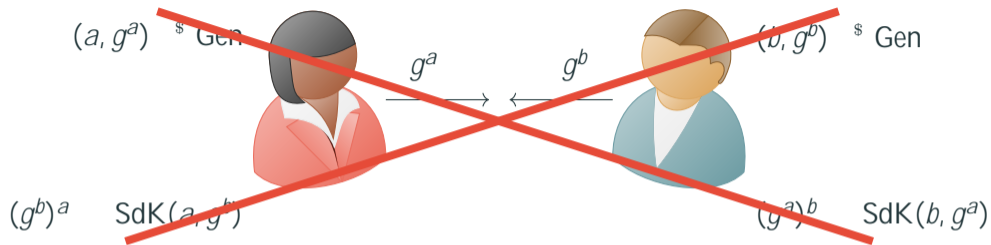


replacing diffie-hellman



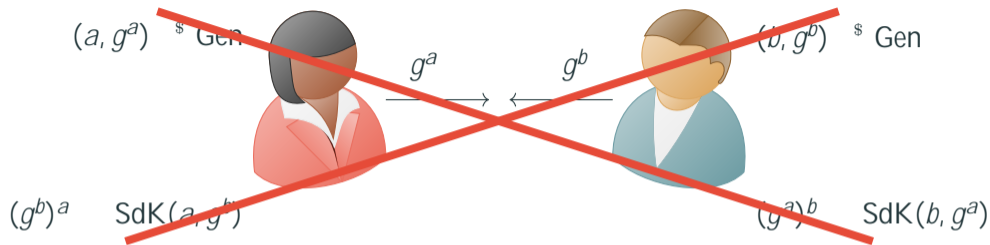
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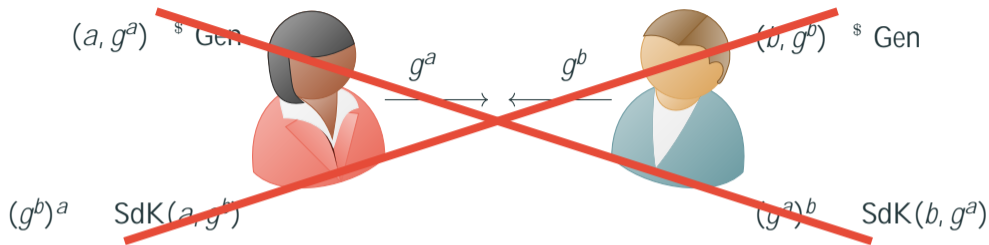
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- | Need a post-quantum replacement

replacing diffie-hellman



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- | Need a post-quantum replacement
- | Folklore: *"Lattice-based non-interactive key exchange is impractical"*
 - | Impossibility results [GKRS20]

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- | Folklore: *"Lattice-based non-interactive key exchange is impractical"*
 - | Impossibility results [GKRS20]
- | Our work: *"It's not **that** bad"*

outline

- | NIKE vs. KEM Applications
- | Scheme: Passive-Swoosh
- | Security Model

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- | Security Model
- | Parameter choices
- | Implementation details
- | Comparison

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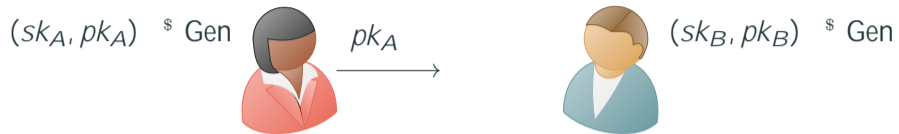
$(sk_A, pk_A) \stackrel{\$}{\text{Gen}}$



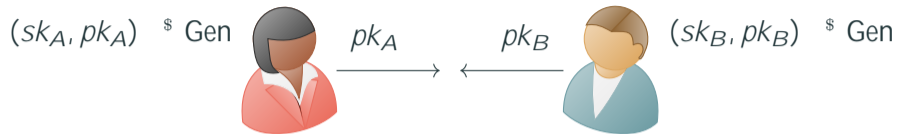
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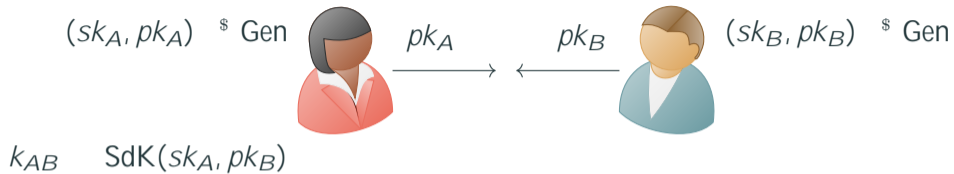
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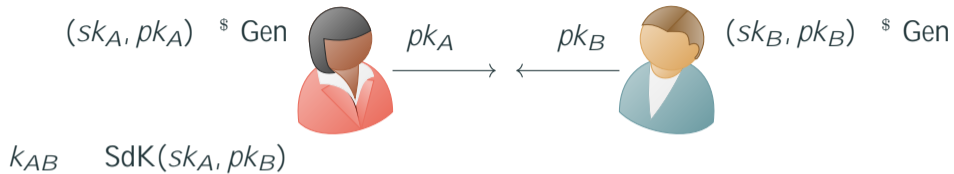
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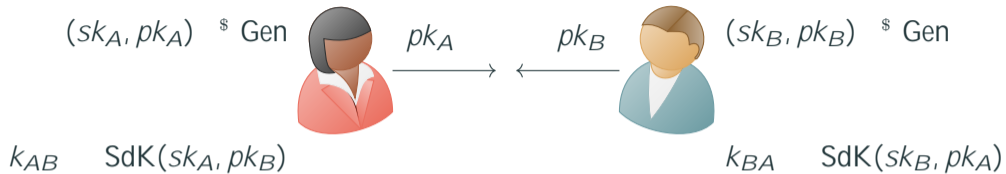
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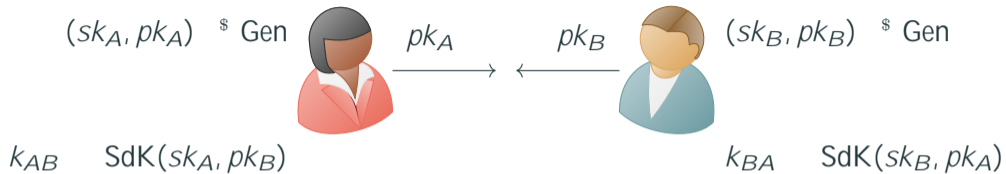
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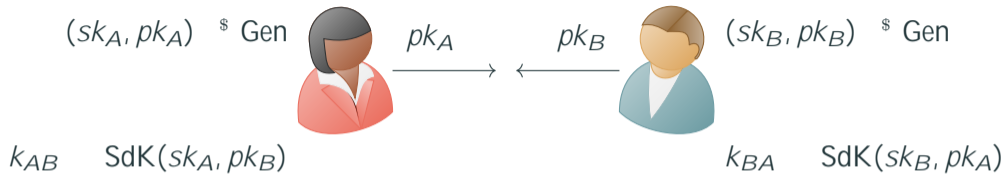
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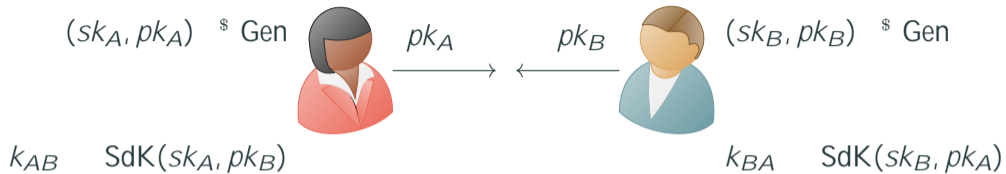
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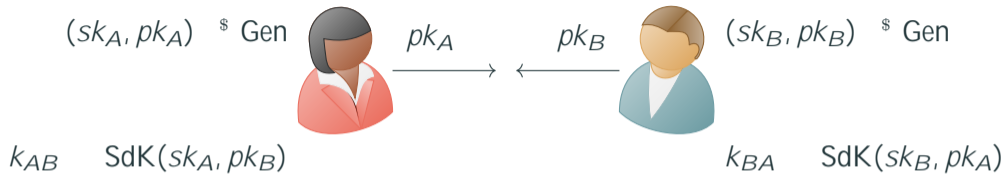
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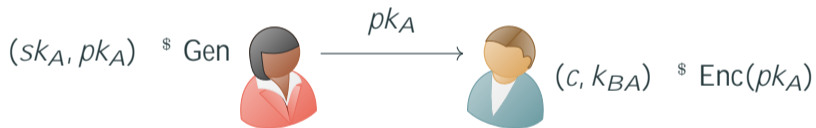
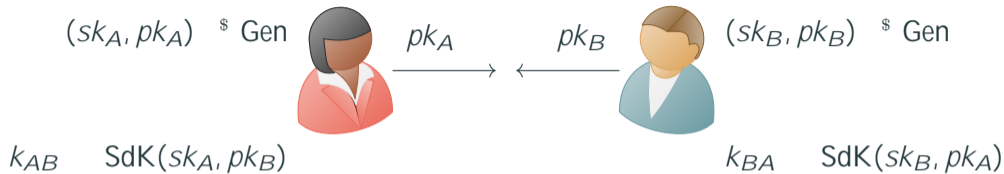
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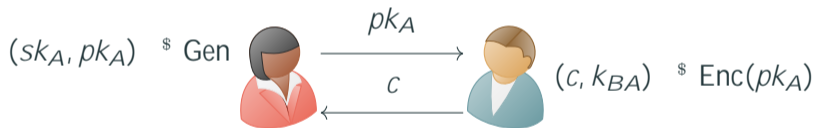
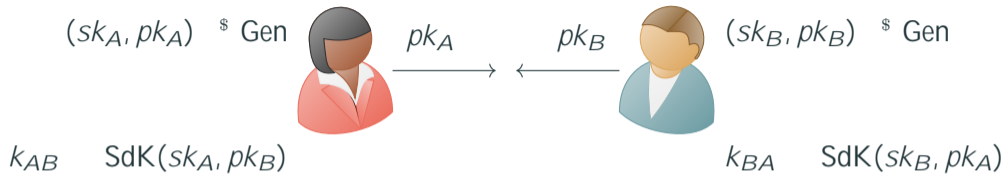
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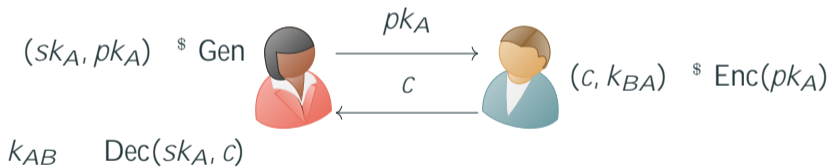
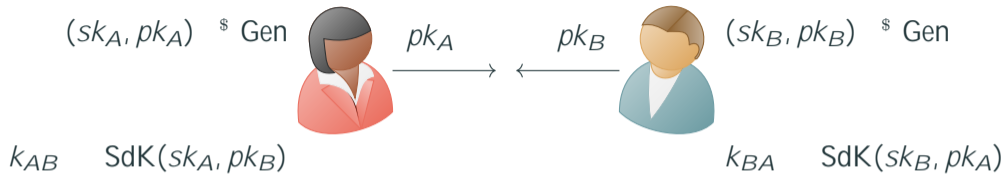
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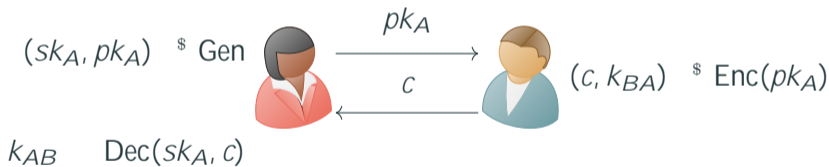
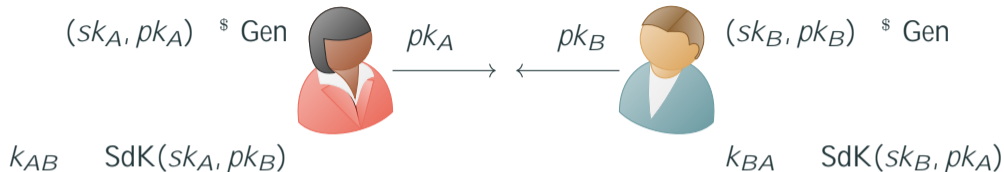
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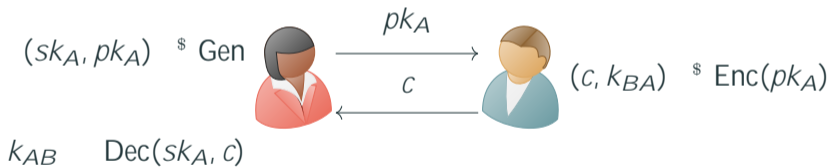
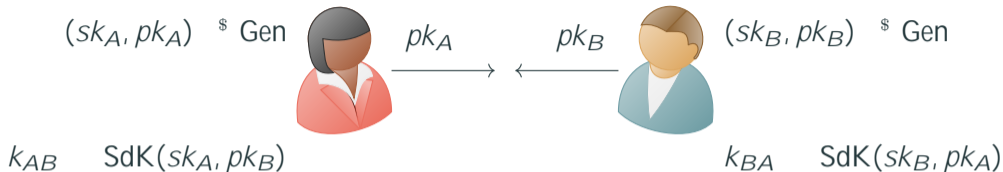


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 - | OPTLS [KW16]
- | Asynchronous key agreement
 - | X3DH [MP16]
- | Other
 - | EDHOC [SMP24]
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 - | More?

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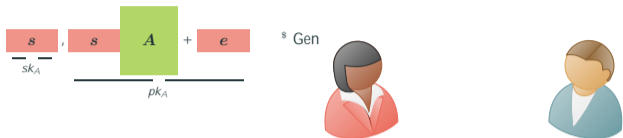
Lattice-based nike has imperfect correctness

s
 sk_A

s Gen



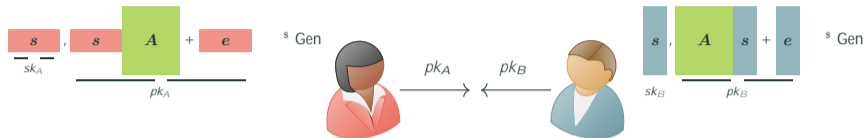
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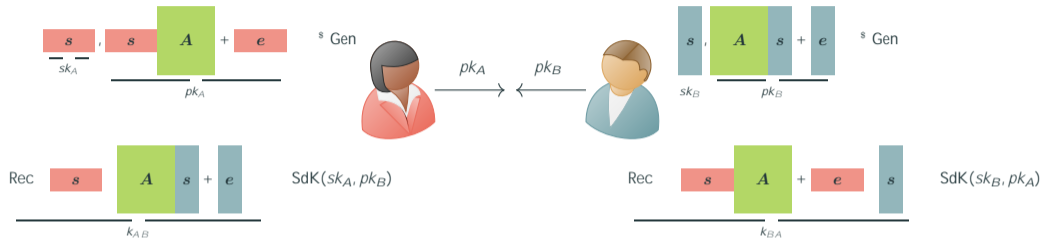
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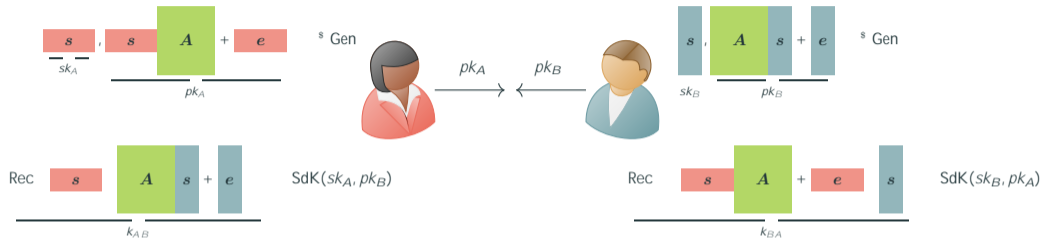
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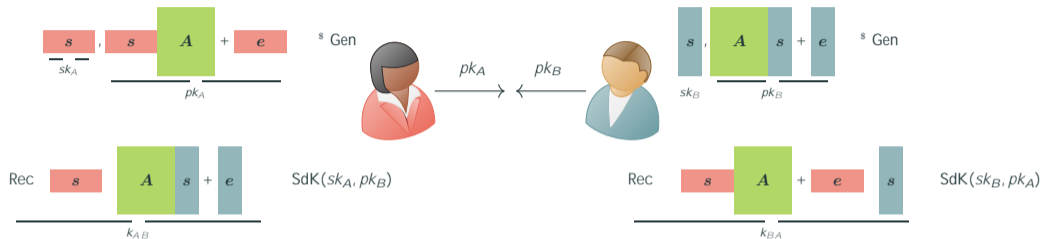


Correctness:

$$:= \Pr \text{ Rec } \left[\begin{array}{c} s \\ A \\ s \end{array} + \begin{array}{c} s \\ e \end{array} \right] = \Pr \text{ Rec } \left[\begin{array}{c} s \\ A \\ s \end{array} + \begin{array}{c} e \\ s \end{array} \right] \frac{4}{q} \frac{2d^2 N}{q}$$

Security: k_{AB} and k_{BA} look random under the M-LWE assumption.

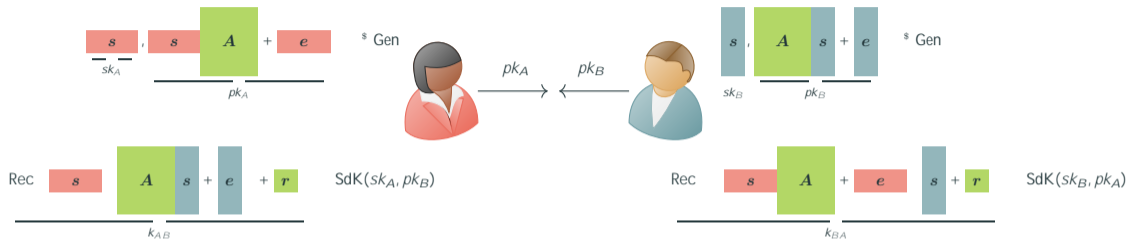
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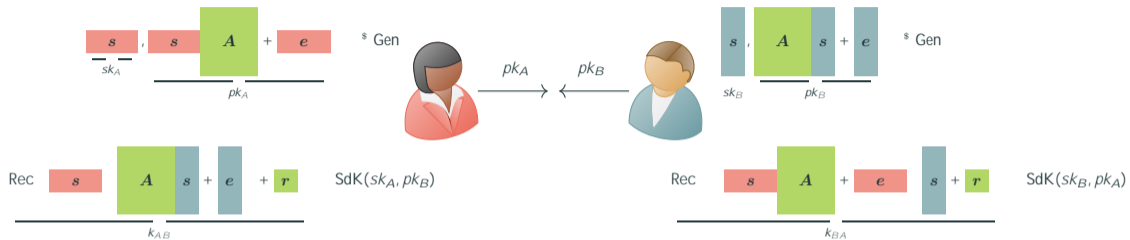
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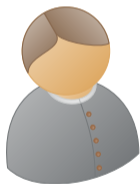
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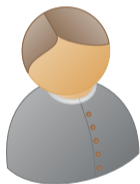
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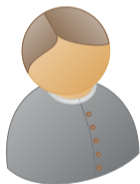
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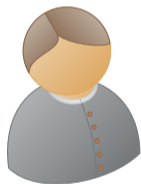


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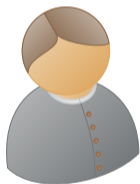
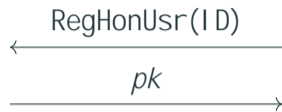


if $b = b$
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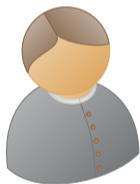
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RegHonU_{sr}(ID)

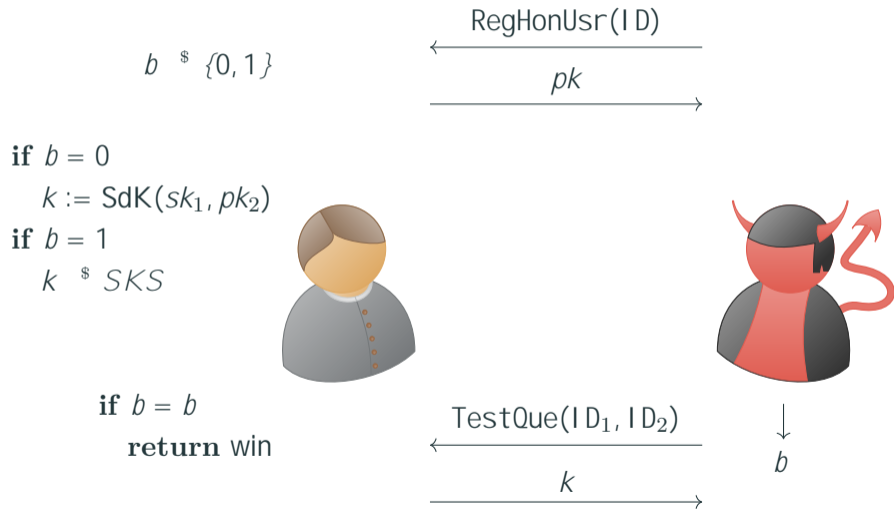


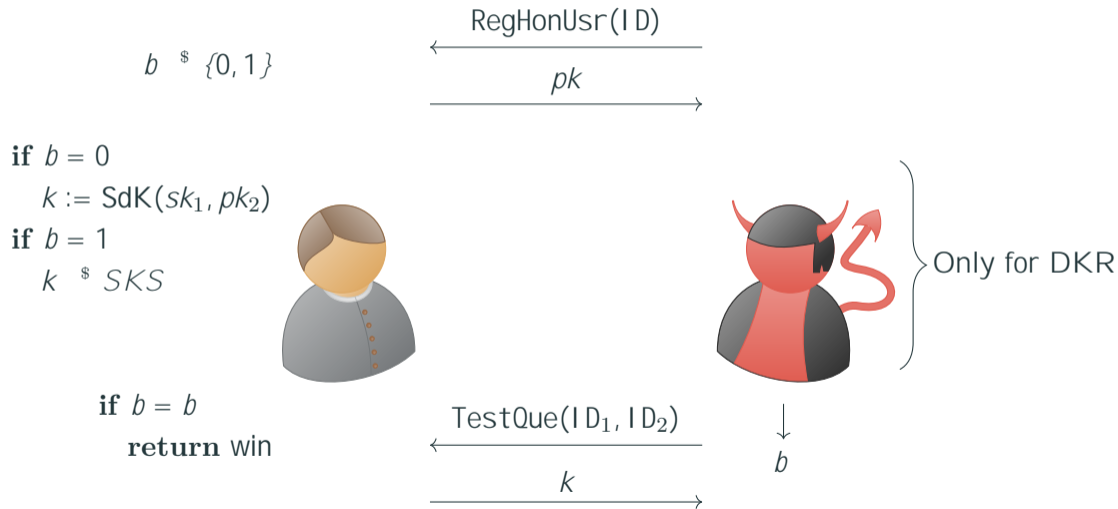
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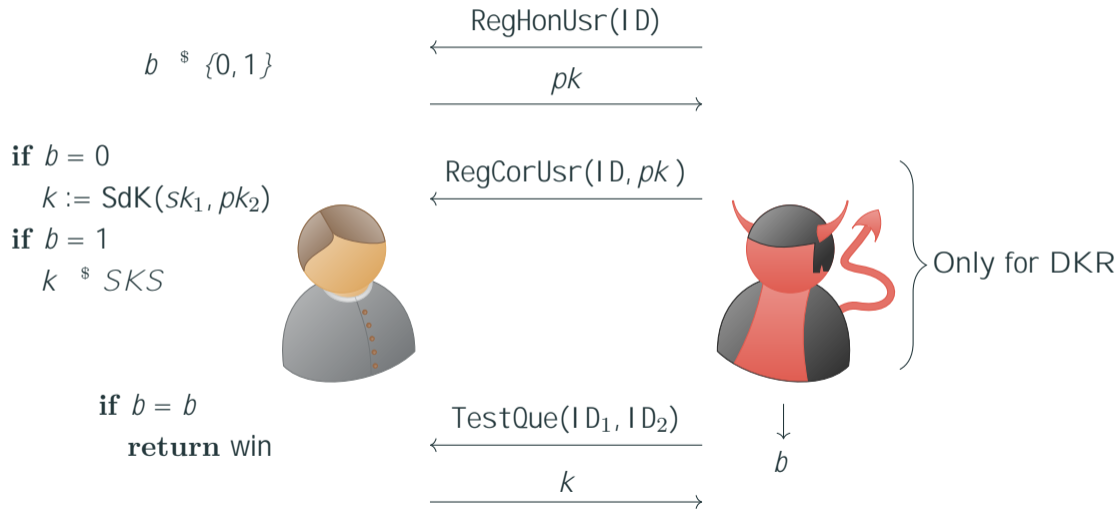
TestQue(ID₁, ID₂)

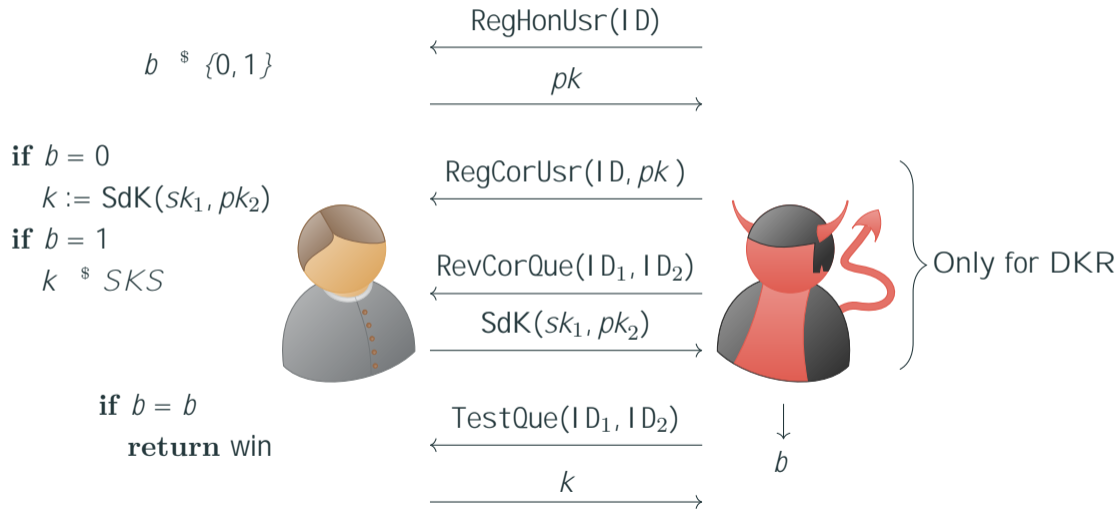


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- | Diffie-Hellman has active security “almost for free” due to perfect correctness
- | Passive-Swoosh needs:
 - | Semi-malicious correctness
 - | Non-interactive zero-knowledge (NIZK) proof of knowledge
 - | \mathcal{A} must know the corresponding secret key of the public key

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parameters and implementation

Parameter	Description	Value
	upper bound on $s = e$	1
q	prime modulus	$2^{214} - 255$
d	dim of $R_q := \mathbb{Z}_q[X]/(X^d + 1)$	256
l	# factors $X^d + 1$ splits into mod q	128
N	height of the \mathbf{A} matrix	32
n	lattice dimension	8192
	secret / noise distribution (ternary)	$p(-1) = 25\%$ $p(0) = 50\%$ $p(1) = 25\%$

- | **Passive-Swoosh** (Semi-malicious correctness) implementation in Rust and Jasmin¹
 - | NIZK not included
 - | Performance penalty depends on context
- | Main optimisation targets
 - | Key Generation Gen
 - | Shared Key Derivation SDK

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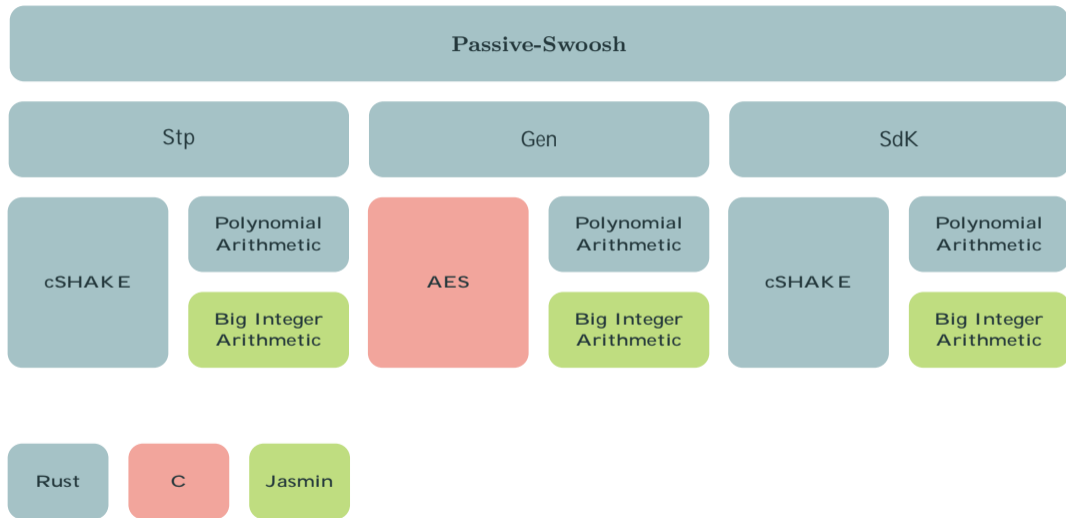
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implementation: overview



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- I Polynomial multiplication:

 - I Number Theoretic Transform (NTT) 10%

 - I Big Integer Arithmetic

- I Noise sampling

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- I Random σ set computation



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implementation: noise generation & random offset computation

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- I Coefficients sampled from *Centered Binomial Distribution* (CBD)
- I CBD generated from output of a *Pseudo-Random Function* (**PRF**)
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- | **Ternary** coefficients computed from two bits using signed reduction modulo 3

| Random offset computation

$r := H(pk_A, pk_B)$

- | Rejection sampling on output of an *eXtendable Output Function* (**XOF**)

| Instantiation of primitives dictates performance: AES256-CTR² & cSHAKE-256

²<https://bench.cr.yp.to/impl-stream/aes256ctr.html>

comparison of select post-quantum kems and nikes

Scheme (variant)	Assumption	PQ ³	NI ⁴	Size (bytes)		Cycles	
				<i>c</i>	<i>pk</i>	Gen	Enc + Dec or SdK
ECDH (X25519)	CDH	7	3	—	32	28 187	87 942
CRYSTALS-Kyber (Kyber-768)	M-LWE	3	7	1 088	1 184	200 302	539 108
Classic McEliece (mceliece348864)	Binary Goppa Codes	3	7	96	261 120	46 715 060	143 178
CTIDH (CTIDH-1024)	CSIDH	3	3	—	128	469 520 000	511 190 000
This work (Passive-Swoosh)	M-LWE	3	3	—	221 184	146 920 890	10 612 666

³Post-quantum

⁴Non-interactive

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- | Diffie-Hellman is most efficient but not PQ secure
- | PQC KEMs are faster than Passive-Swoosh but require interaction
- | PQ NIKEs: trade-off between key size and speed

³Post-quantum

⁴Non-interactive

summary

Contributions:

- | M-LWE based NIKE, with strong correctness and proof in the QRROM.
 - | Generic transformation from passive to active security using NIZKs.
- | Optimised implementation of Passive-Swoosh, written in Rust and Jasmin.
 - | Parameters achieving 120 bits of security against quantum adversaries.
 - | Smaller public keys than Classic McEliece KEM and faster than CTIDH NIKE.



ia.cr/2023/271 — github.com/MQuaresma/pswoosh



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