PQCRYPTO
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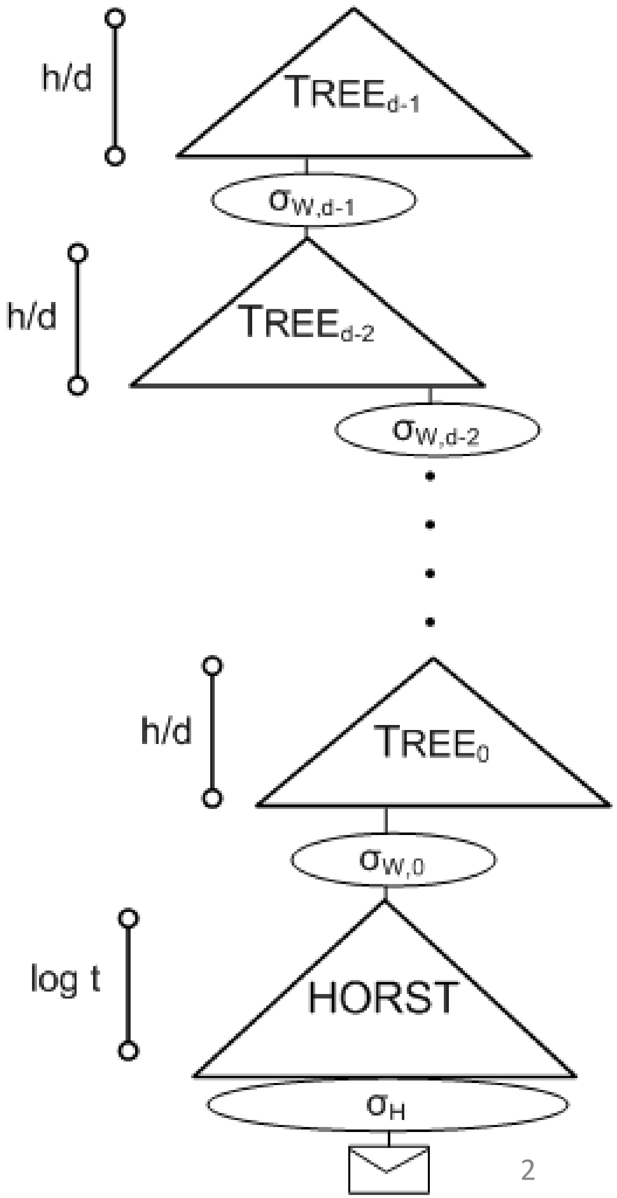
SPHINCS$^+$

Submission to the NIST post-quantum project

Daniel J. Bernstein, Christoph Dobraunig, Maria Eichlseder, Scott Fluhrer, Stefan-Lukas Gazdag, Andreas Hülsing, Panos Kampanakis, Stefan Kölbl, Tanja Lange, Martin M. Lauridsen, Florian Mendel, Ruben Niederhagen, Christian Rechberger, Joost Rijneveld, Peter Schwabe

The SPHINCS Approach

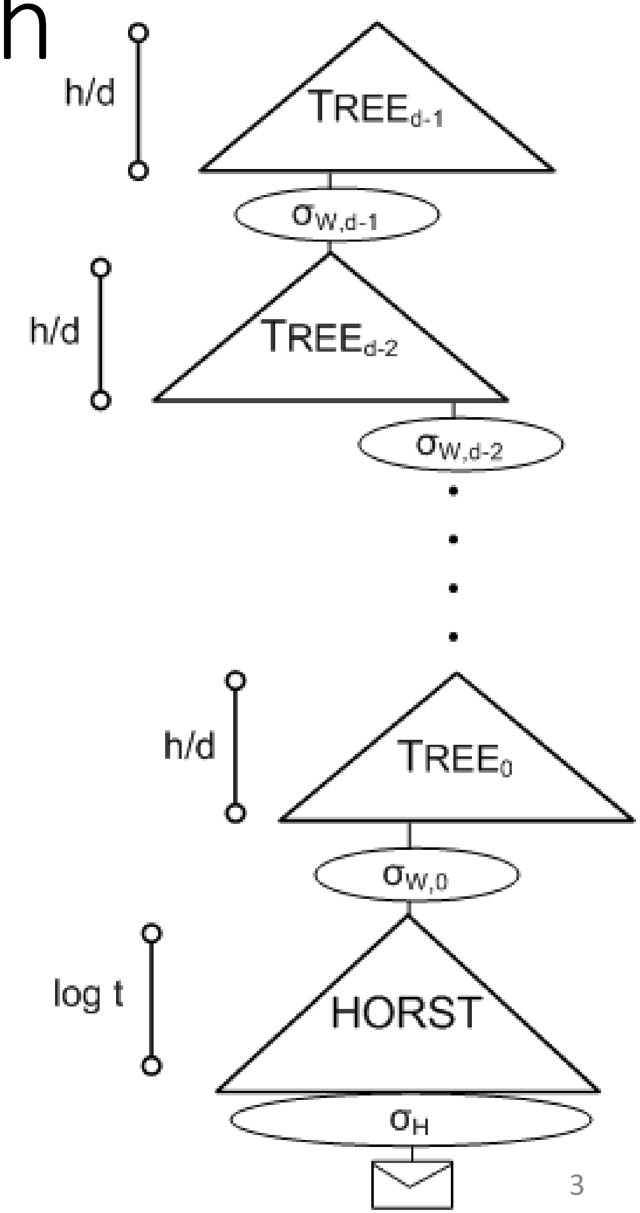
- Use a “hyper-tree” of total height h
- Parameter $d \geq 1$, such that $d \mid h$
- Each (Merkle) tree has height h/d
- (h/d)-ary certification tree



The SPHINCS Approach

- Pick index (pseudo-)randomly
- Messages signed with few-time signature scheme
- Significantly reduce total tree height
- Require

$$\sum_{r\in[0,\infty]}(\Pr[\text{ r} - \text{times index collision}]\; * \; Succ^{\text{HORST}}_{\text{EU}-\text{CMA}}(A, q = r)) \; = \; \text{negl}(n)$$



SPHINCS$^+$ modifications

Adding multi-target attack resilience

- Preimage search:

$$\mathrm{Succ}^{\mathrm{OW}}_{\mathcal{H}_n}\left(\mathcal{A}\right) = \left(\frac{q+1}{2^n}\right),$$

- Multi-target preimage search:

$$\mathrm{Succ}^{\mathrm{SM\text{-}OW}}_{\mathcal{H}_n,p}\left(\mathcal{A}\right) = \left(\frac{(q+1)p}{2^n}\right),$$

- Multi-function multi-target preimage search

$$\mathrm{Succ}^{\mathrm{MM\text{-}OW}}_{\mathcal{H}_n,p}\left(\mathcal{A}\right) = \left(\frac{q+1}{2^n}\right),$$

Tweakable hash functions

$$T_l\colon\ \mathbb{B}^n \times \mathbb{B}^{32} \times \mathbb{B}^n \rightarrow \mathbb{B}^n,$$
$$\mathrm{md} \leftarrow T_l(\mathbf{PK}.\,\mathrm{seed}, \mathbf{ADRS}, M)$$

- Generates new keys and bitmasks for each call from **PK**.seed and **ADRS**.
- Allows to embed one challenge per call in reduction

Why not collision resistance?

- Bernstein, SHARCS‘09:
  pq-collision finding costs at least $2^{n/2}$
- Same as cost for pq-(second-)preimage finding?
- **No!** Comparing apples and oranges. Compares cost fr pq-(second-)preimage finding in query complexity model to cost for pq-collision finding in more realistic model.
- Also stronger complexity-theoretic assumption!
  (Minicrypt vs (conj.) Cryptomania)

FORS

Shortcomings of HORST

- „index collisions“
  - Allows to search for weak messages (no impact on SPHINCS as hash randomized)
  - Still reduces security
- Indices are in unordered list
- Authentication paths will most likely contain redundant nodes
  - Variable size signatures could go lower but requires complicated algorithm (and protocols have to reserve worst-case size) -> see Gravity-SPHINCS‘s Octopus

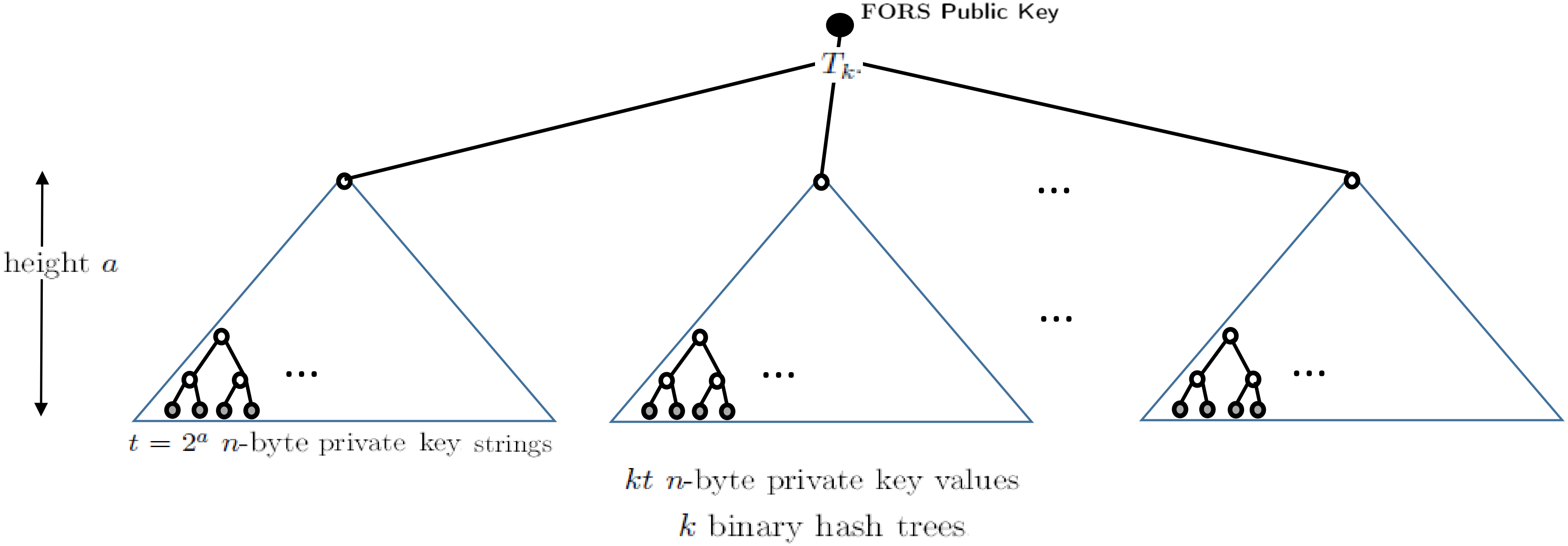
FORS

FORS (Forest of random subsets)

- No index collisions
  - „One tree per index“
- Ordered list of indices
- Signature size same as worst-case variable signature size (at same security level)
  - Only need authpaths in small trees
  - Simple to compute

FORS

- Parameters t, a = log t, k such that ka = m


FORS Public Key
T_k
height a
...
$t = 2^a$ n-byte private key strings
kt n-byte private key values
k binary hash trees

Verifiable index selection

(and optionally non-deterministic randomness)

- SPHINCS:

$$(\mathrm{idx}||\mathbf{R}) \;=PRF(\mathbf{SK}.\mathrm{prf}, M)$$
$$\mathrm{md} = \; H_{\mathrm{msg}}\,(\mathbf{R}, \mathrm{PK}, M)$$

- SPHINCS^{+}:

$$\mathbf{R} \;= \; PRF(\mathbf{SK}.\mathrm{prf}, \mathrm{OptRand}, M)$$
$$(\mathrm{md}||\mathrm{idx}) \;= \; H_{\mathrm{msg}}\,(\mathbf{R}, \mathrm{PK}, M)$$

Optionally non-deterministic randomness

- Non-deterministic randomness complicates side-channel attacks

- Bad randomness in worst-case still leads to secure pseudorandom value

Verifiable index selection

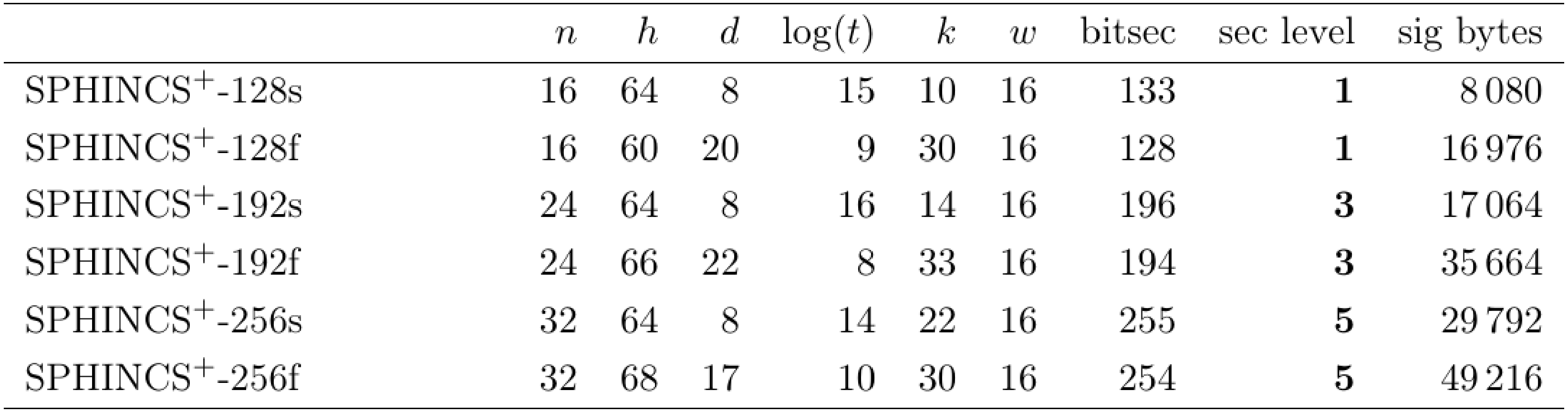
Improves FORS security

- SPHINCS: Attacks could target „weakest“ HORST key pair
- SPHINCS$^+$: Every hash query ALSO selects FORS key pair
    - Leads to notion of interleaved target subset resilience

Instantiations

- SPHINCS$^+$-SHAKE256
- SPHINCS$^+$-SHA-256
- SPHINCS$^+$-Haraka

Instantiations (small vs fast)



	n	h	d	$\log(t)$	k	w	bitsec	sec level	sig bytes
SPHINCS$^+$-128s	16	64	8	15	10	16	133	**1**	8 080
SPHINCS$^+$-128f	16	60	20	9	30	16	128	**1**	16 976
SPHINCS$^+$-192s	24	64	8	16	14	16	196	**3**	17 064
SPHINCS$^+$-192f	24	66	22	8	33	16	194	**3**	35 664
SPHINCS$^+$-256s	32	64	8	14	22	16	255	**5**	29 792
SPHINCS$^+$-256f	32	68	17	10	30	16	254	**5**	49 216

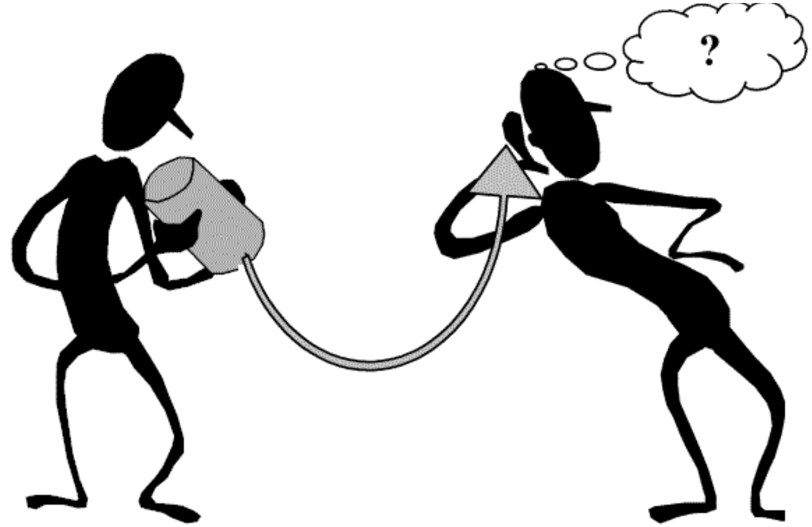
Pro / Con

- Con: Signature size / speed
- Pro: Only secure hash needed
- Pro: Collision-resilient
- Pro: Attacks are well understood (also quantum)
- Pro: Small keys
- Pro: Overlap with XMSS
- Pro: Reuse of established building blocks

Summary of SPHINCS$^+$

- Strengthened security gives smaller signatures
- Collision- and multi-target attack resilient
- Fixed length signatures (far easier to compute than Octopus (-> Gravity-SPHINCS))
- Small keys, medium size signatures (lv 3: 17kB)
- Sizes can be much smaller if q_sign gets reduced
- THE conservative choice
- No citable speeds yet

Thank you!
Questions?



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