Tweakable Hash Functions in Stateless Hash-Based Signature Schemes

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Mathematical Foundations of Cryptography

Motivation & Outline

hash functions are...

- well understood
- fast
- active research topic!
- e.g. signatures
- theoretical background
- proofs and notions

Contents

Hash-Based Signature Schemes

Hash-Based Signature Schemes[KF17]

- initially: Merkle Tree Signatures against Quantum Computers[Aug+17]
- minimal security assumptions
- One-Time Signatures
  - Lamport Signatures
  - WOTS/WOTS+
  - BiBa
  - ...
- Merkle Signatures
- XMSS and $XMSS^{MT}$
- stateful! keep track of all produced signatures

SPHINCS+[Aum+17]

- *Stateless Practical Hash-based Incredibly Nice Cryptographic Signatures*
- NIST Post-Quantum Project, Round 2
- small keys
- simple building blocks
- *stateless*: large structure (Goldreich)

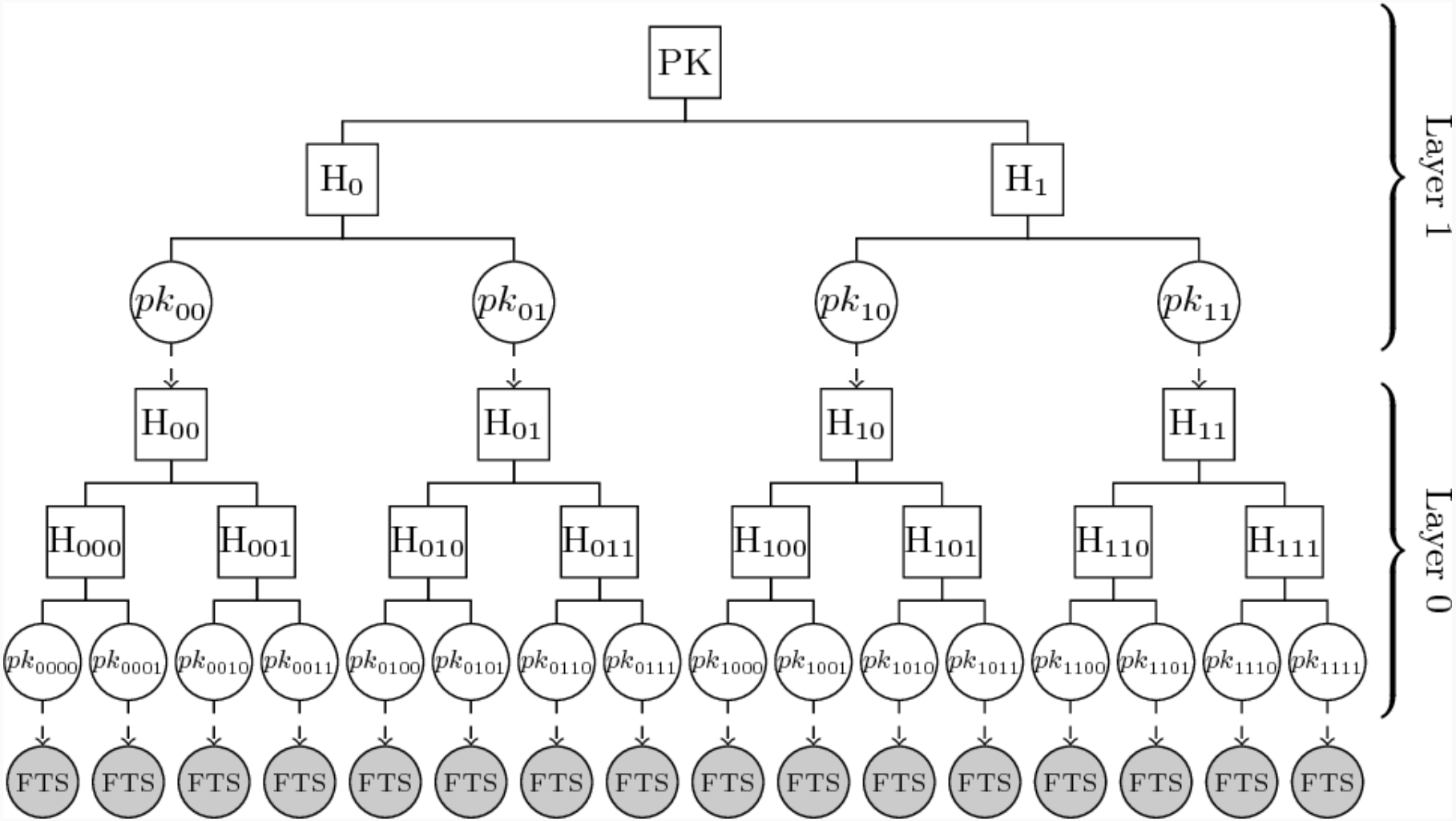

Figure 1: An overview of SPHINCS+, original picture from [CMP18]

Interlude: Proving Correctness [GHS15][Bin+19]

- **classical generic security**
  success probability against a random function family
- **quantum generic security**
  random function with superposition queries
- used primitive is still classical
- Random Oracle Model (ROM)
- Quantum Random Oracle Model (QROM)

Tweakable Hash Functions

Tweakable Hash Function[Ber+19]

- unify security analysis of hash-based signature schemes
- indifferent of used function
- independent calls
- three possible constructions

Tweakable Hash Function[Ber+19]

- *tweak* $T \in \mathcal{T}$
  context information, nonce
  `ADRS`
- *public parameters* $P \in \mathcal{P}$
  `PK.seed`
- $\mathbf{Th} : \mathcal{P} \times \mathcal{T} \times \{0,1\}^{\alpha} \to \{0,1\}^{n}$
  $MD \leftarrow \mathbf{Th}(P, T, M)$
- $\mathcal{P} = \{0,1\}^{n}$, $\mathcal{T} = \{0,1\}^{256}$
- Great, let's build one! (or three)

1^{st} approach to the construction of a Tweakable Hash Function

- standard model using a keyed hash function

$$H : \mathcal{K} \times \{0,1\}^{\alpha} \rightarrow \{0,1\}^{n}$$
$$\mathbf{Th}(P, T, M) = H(P_t, M^{\oplus})$$
$$P_t = P[(\alpha + n)T, n]$$
$$M^{\oplus} = M \oplus (P[(\alpha + n)T + n, \alpha])$$

- requires P to be linear to the size of the tweak space
- exponential-size public parameters: not suitable

2^{nd} approach to the construction of a Tweakable Hash Function[HRS16]

- two hash functions H_1 and H_2

$$H_1 : \{0,1\}^{2n} \times \{0,1\}^{\alpha} \rightarrow \{0,1\}^{n}$$
$$H_2 : \{0,1\}^{2n} \rightarrow \{0,1\}^{n}$$

2^{nd} approach to the construction of a Tweakable Hash Function[HRS16]

- two hash functions H_1 and H_2
- ~~public parameters~~ short public seed

$$H_1 : \{0,1\}^{2n} \times \{0,1\}^{\alpha} \rightarrow \{0,1\}^{n}$$
$$H_2 : \{0,1\}^{2n} \rightarrow \{0,1\}^{n}$$
$$\mathbf{Th}(P, T, M) = H_1(P||T, M^{\oplus})$$
$$M^{\oplus} = M \oplus H_2(P||T)$$

2^{nd} approach to the construction of a Tweakable Hash Function[HRS16]

- two hash functions H_1 and H_2
- ~~public parameters~~ short public seed

$$H_1 : \{0,1\}^{2n} \times \{0,1\}^{\alpha} \to \{0,1\}^{n}$$
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- secure under the standard model
- require a QROM for public-parameter compression

3^{rd} approach to the construction of a Tweakable Hash Function

- assume all hash functions behave like QROs
- similar to LMS signatures-
  distinct prefix and suffix to avoid multi-collision attacks

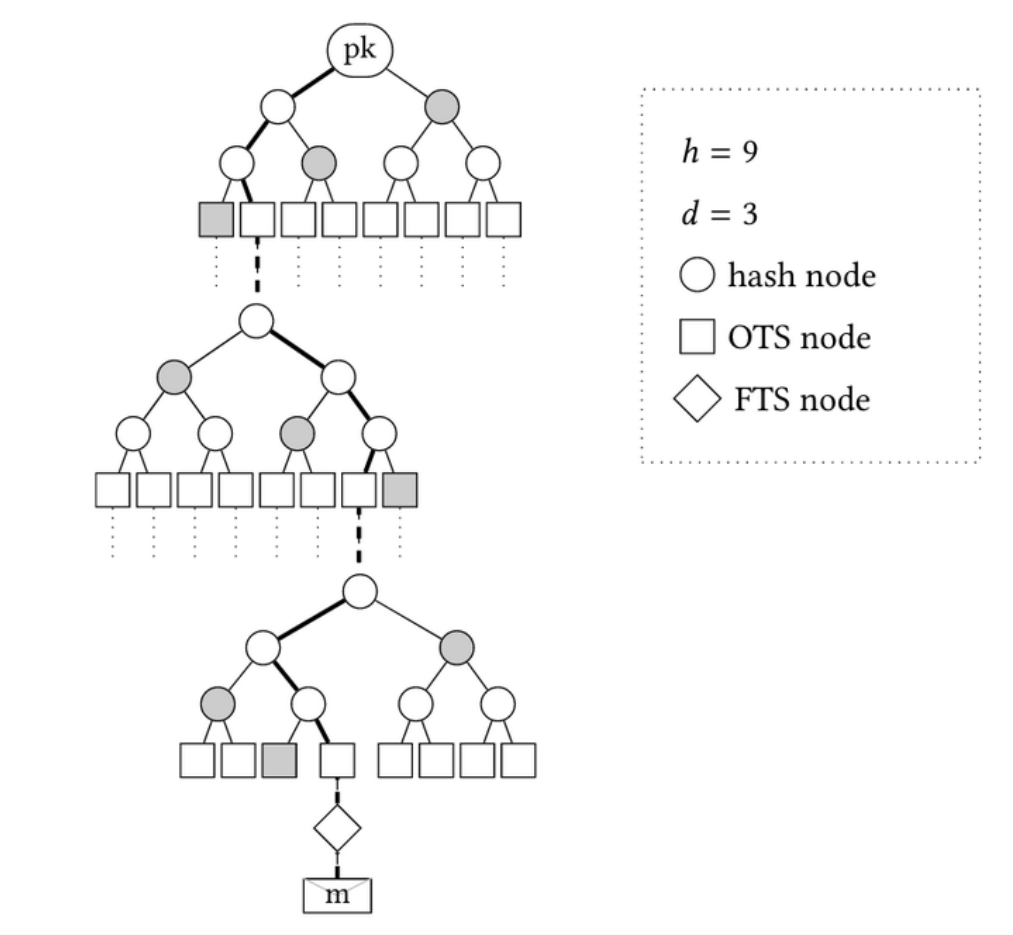
$$H : \{0,1\}^{2n+\alpha} \rightarrow \{0,1\}^n$$

$$\mathbf{Th}(P, T, M) = H(P||T||M)$$

Tweakable Hashes in SPHINCS+

Tweakable Hashes in SPHINCS+

- six different instantiantions
- using 2^{nd} or 3^{rd} approach
- SHA-256, SHAKE256 and Haraka
- *PQ-EU-CMA*



Cryptographic (Hash) Function Instantiation

- tweakable hash functions
  - limit message length to multiples of n
- pseudorandom functions
  - key and randomness generation
  - process messages of arbitrary length

Thank you for your attention!

If you have any questions, please do not hesitate to ask!

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